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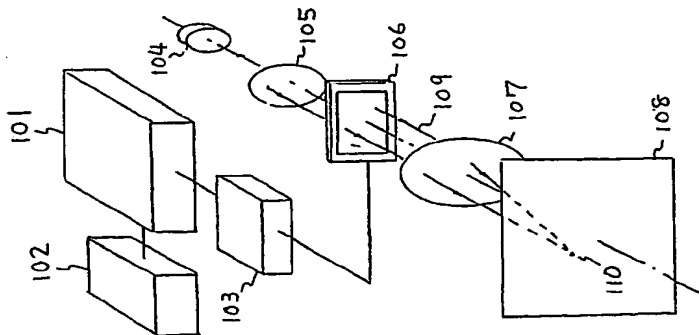
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(54) **Optical apparatus.**

(57) An optical apparatus for controlling a wave front of a coherent light includes at least a coherent light source (104), an electrically addressable liquid cry-

stal device (106) having a plurality of pixels, and a signal generator (101-103) for recording a complex amplitude distribution on said liquid crystal device.

**FIG. 1****EP 0 451 681 A2**

The present invention relates to an optical apparatus which uses a liquid crystal device.

Holography has commonly been used as means for controlling the wave front of coherent light. Various types of information apparatus which use a holographic device have been developed and part of them have been put into practical use such as a laser scanner or an optical disk head.

However, since the holographic device is manufactured using a recording material, such as a silver halide photo-sensitive emulsion or a resist, it must be reconstructed each time the requirements for the holographic device alter. The man-hours and equipment investment required for reconstruction are a great burden to the manufacturer.

In view of the aforementioned problem of the conventional techniques, it is an object of the present invention to provide an optical apparatus having a programmable function for controlling a light wave front which is achieved by the incorporation of a liquid crystal device exhibiting desired light wave modulation characteristics.

Embodiments of the present invention will now be described with reference to the accompanying drawings, in which

Fig. 1

is a perspective view of a first embodiment of an optical apparatus according to the present invention;

Figs. 2(a) and 2(b)

are plan views, respectively, showing modifications of the first embodiment of the present invention;

Fig. 3(a)

is a plan view showing the external view of an electrically addressed transmission type liquid crystal device;

Fig. 3(b)

is a plan view showing the pixel arrangement of the electrically addressed transmission type liquid crystal device;

Fig. 4

is a graph showing the phase modulation characteristics of a TN mode liquid crystal device;

Fig. 5

is a graph showing the amplitude modulation characteristics of the TN mode liquid crystal device;

Fig. 6

is a graph showing the phase modulation characteristics of an ECB mode liquid crystal device;

Fig. 7

is a graph showing the amplitude modulation characteristics of the ECB mode liquid crystal device;

Fig. 8

is a cross-sectional view of an electrically addressed reflection type liquid crystal device;

Fig. 9

explains a first method of optically addressing a liquid crystal display member using an electrically addressed transmission type liquid crystal device;

Fig. 10

explains a second method of optically addressing a liquid crystal display member using an electrically addressed transmission type liquid crystal device;

Fig. 11

shows the concept of reduction projection of the two-dimensional images recorded on electrically addressed transmission type liquid crystal devices;

Fig. 12

explains a third method of optically addressing a liquid crystal display member using an electrically addressed transmission type liquid crystal device;

Fig. 13

shows the concept of the positional relation between the pixels of an active device;

Fig. 14

is a plan view of a seventh embodiment of the present inventions;

Fig. 15(a) and 15(b)

respectively show amplitude distribution of a kinoform;

Fig. 16

is a plan view of an eighth embodiment of the present invention;

Figs. 17 (a) and 17(b)

are a plan view and a partially enlarged cross-sectional view, respectively, of a ninth embodiment of the present invention;

Fig. 18(a)

shows a lens recorded on a liquid crystal device, showing a tenth embodiment of the present invention;

Fig. 18(b)

shows how the lens recorded on the liquid crystal device converges light in the tenth embodiment of the present invention;

Figs. 19(a) and 19(b)

respectively show a plurality of lenses recorded on the liquid crystal device in an eleventh embodiment of the present invention;

Fig. 20(a)

shows a plurality of lenses recorded on the liquid crystal device in a twelfth embodiment of the present invention;

Fig. 20(b)

shows how the plurality of lenses recorded on the liquid crystal device converges light in the twelfth embodiment of the present invention;

Fig. 20(c)

is a partially enlarged cross-sectional view of the

twelfth embodiment of the present invention;

Fig. 21

is a perspective view of a thirteenth embodiment of the present invention;

Fig. 22

shows various wiring patterns;

Fig. 23

is a perspective view of a fourteenth embodiment of the present invention;

Fig. 24

is a plan view of a fifteenth embodiment of the present invention;

Fig. 25

is a plan view of a sixteenth embodiment of the present invention;

Fig. 26

is a plan view of an eighteenth embodiment of the present invention;

Fig. 27(a)

is a perspective view of a three-dimensional formed model;

Fig. 27(b)

is a cross-sectional view of a three-dimensional formed article;

Fig. 28

is a plan view of a nineteenth embodiment of the present invention;

Fig. 29

is a plan view of a twentieth embodiment of the present invention;

Fig. 30

is a plan view of a twenty-first embodiment of the present invention;

Fig. 31

is a plan view of a twenty-second embodiment of the present invention;

Fig. 32

explains an aberration of a liquid crystal panel; and

Fig. 33

is a plan view of a twenty-third embodiment of the present invention.

#### First Embodiment

Fig. 1 shows the configuration of an optical apparatus according to the present invention. A laser beam 109 emanating from a laser beam source 104 is converted into parallel rays of light by means of a collimator lens 105. The resultant light illuminates a liquid crystal device 106 which modulates the wave front of the incident light by the action of a computer-generated hologram recorded on the liquid crystal device 106. The modulated light passes through a lens 107 and then forms a laser beam spot or a spot row 110 on a predetermined output screen 108.

A video signal for recording the computer-gen-

erated hologram on the liquid crystal device 106 is created by a personal computer (PC) 101. The signal is input to the liquid crystal device 106 through an interface circuit 103. The birefringence of each pixel of the liquid crystal device 106 changes in accordance with the level of the input signal, by which amplitude modulation of the wavefront of the laser beam is performed. The computer-generated hologram recorded on the liquid crystal device 106 can be rewritten at a high speed by reading out the pattern data stored in a video memory 102 of the PC 101 beforehand in sequence.

Fig. 2 shows another configuration of the optical apparatus according to the present invention. In Fig. 2(a), an optical path is bent using two mirrors 201 and 202. In Fig. 2(b), a laser beam propagates between two light guiding plates 211 and 212.

With the configurations shown in Figs. 2(a) and 2(b), it is possible to reduce the size of the optical apparatus.

Fig. 3(a) shows the external view of an example of a liquid crystal device 301 which is the major component of the optical apparatus according to the present invention. This liquid crystal device has the following features:

(1) There is no crosstalk between the pixels because of the provision of a poly-Si TFT (a thin-film transistor) as an active element for each pixel.

(2) The size is small because of a built-in driver.

(3) The display area 302 having dimensions of 19 mm x 14 mm has 320 pixels in the horizontal direction and 220 pixels in the vertical direction.

Fig. 3(b) is an enlarged plan view of the display area of the liquid crystal device 301. The pixels 311 are arranged in the form of a regularly lattice equally spaced from each other both horizontal and vertical direction.

The TFTs and other circuit elements are disposed below a light blocking mask 312 in order to avoid malfunction caused by the irradiation of light.

The use of the liquid crystal device having the aforementioned features enables the laser beam spot arrangement having a desired intensity distribution to be freely generated.

In the optical apparatus according to the present invention, the computer-generated hologram comprises a Fourier transform type amplitude hologram which is characterized in that single Fourier data is expressed using nine pixels 311.

The liquid crystal device shown in Fig. 3 and used in the optical apparatus according to the present invention includes a twisted-nematic (TN) mode liquid crystal panel and two polarizing plates disposed on the two sides of the panel. In this invention, the directions of the axes of these ele-

ments have the following relationship.

- (1) The directions of the axes of the two polarizing plates are orthogonal to each other.
- (2) The direction of transmission of the front polarizing plate is perpendicular to the director of the liquid crystal molecules on the incident surface.

The above-described arrangement of the components of the liquid crystal device 301 is necessary for the following reasons.

In the optical apparatus according to the present invention, the computer-generated hologram is recorded on the liquid crystal device using the two-dimensional amplitude distribution alone. However, in the TN mode liquid crystal device, there generally occurs not only an amplitude change but also a phase shift (Opt.Lett. 13, 251-253 (1988)). Hence, the directional relation between the liquid crystal panel and the polarizing plates, which assures the smallest possible phase shifts, must be obtained.

Fig. 4 is a graph showing the relationship between the phase shift and the voltage applied to the liquid crystal panel, obtained in the four fundamental conditions under which the TN mode liquid crystal panel is used. In Fig. 4, curve 1 denotes the case where the directions of the two polarizing plates are parallel to each other while the direction of the front polarizing plate is parallel to the director of the liquid crystal molecules on the incident surface, curve 2 denotes the case where the directions of the polarizing plates are parallel to each other while the front polarizing plate is orthogonal to the director of the liquid crystal molecules on the incident surface, curve 3 denotes the case where the directions of the two polarizing plates are orthogonal to each other while the direction of the front polarizing plate is parallel to the director, and curve 4 denotes the case where the directions of the polarizing plates are orthogonal to each other while the direction of the front polarizing plate is orthogonal to the director.

As is clear from Fig. 4, the phase shift is the smallest when the directions of the polarizing plates are orthogonal to each other while the direction of the front polarizing plate is orthogonal to the director.

Fig. 5 is a graph showing the relationship between the applied voltage and the amplitude change, obtained when the liquid crystal panel and the polarizing plates are arranged in the above-described manner. As will be appreciated, it is possible to obtain a large contrast and a sufficient gradient.

In this way, a high-performance amplitude type computer-generated hologram can be recorded on the liquid crystal device.

As will be understood from the foregoing de-

scription, in the optical apparatus according to the present invention, it is possible to perform highly accurate position control of laser beam and generation of irregular spot arrangement on real-time basis by using wave front reconstruction of the amplitude type computer-generated hologram recorded on the TN mode liquid crystal device.

In this embodiment, a two-dimensional position control of the laser beam has been described. However, control of the laser beam in a three-dimensional space is made possible by exchanging the pattern of the computer-generated hologram.

## Second Embodiment

In this embodiment an electrically controlled birefringence (ECB) mode liquid crystal device is used in place of the TN mode liquid crystal device for the first embodiment.

The liquid crystal device in this optical apparatus according to the present invention includes an ECB mode liquid crystal panel, and a single polarizing plate disposed on the side of the panel on which a laser beam is incident. The liquid crystal molecules in the liquid crystal panel are oriented uniformly parallel to the panel substrate at the initial stage of the operation. The direction of transmission of the polarizing plate is parallel to the plane made by the panel substrate and the director of the liquid crystal molecules.

The above-described structure of the liquid crystal device enables changes in birefringence of the liquid crystal layer, caused by an applied voltage, to be effectively utilized. It is therefore possible to attain excellent phase modulation of the laser beam.

Fig. 6 shows the relationship between the phase shift and the applied voltage, obtained from the ECB mode liquid crystal device. Good linearity of the phase shift can be obtained in the applied voltage range from 1.2 volts to 2.5 volts. That relationship must be maintained on order to achieve phase control of the wavefront of the light by the unit of pixel and hence control of a laser beam. It is clear from Fig. 6 that a phase shift of 2  $\pi$ , required for recording the phase type hologram, can be obtained when the amplitude of the video signal is 2.1 volts.

For the same liquid crystal device as in Fig. 6, Fig. 7 shows the relationship between the transmission and the voltage applied. In Fig. 7, another polarizing plate was disposed on the light emitting side of the liquid crystal device for measurements. The directions of transmission of the two polarizing plates were parallel to each other. It is apparent from Fig. 7 that the transmission, i.e., the square of the amplitude, is substantially constant regardless of the applied voltage. This relationship must be

maintained in order to perform control of a laser beam which is free from disturbance caused by amplitude modulation of the laser beam.

It is possible to record a high-performance phase type computer-generated hologram on the liquid crystal device by utilizing the characteristics shown in Figs. 6 and 7.

The computer-generated hologram used in the optical apparatus of this embodiment is of the Fourier transform type in which pixels and Fourier transform values have a one-to-one correspondence.

In this way, the limited number of pixels can be effectively utilized when a computer-generated hologram is recorded on the ECB mode liquid crystal device.

As will be understood from the foregoing description, in the optical apparatus according to the present invention, highly accurate position control of a laser beam and generation of an irregular laser beam spot arrangement can be performed on a real-time basis utilizing the wavefront reproduction function of the phase type computer-generated hologram recorded on the ECB mode liquid crystal device.

In this embodiment, position control of the laser beam in a two-dimensional space has been described. However, control in a three-dimensional space is made possible by exchanging the pattern of the computer-generated hologram.

### Third Embodiment

This embodiment differs from the first embodiment in that a liquid crystal device having a configuration shown in Fig.8 is used in place of the TN mode liquid crystal device.

First, a method of manufacturing this liquid crystal device will be described.

After a transistor-type active matrix 811 and a matrix electrode 808 are formed on a silicon substrate 810, sealing of an insulating material 809 is conducted. Thereafter, surface etching is conducted to obtain a flat surface. Next, a dielectric mirror 807 is formed by evaporation, and oblique evaporation on the surface of the dielectric mirror 807 is then performed to form an oriented surface 806 for alignment. Then, a liquid crystal 805 is filled into a gap between the dielectric mirror 806 and a glass substrate 802 on which a transparent counter electrode 803 is formed. A polarizing plate 801 is disposed on the outside of the glass substrate 802.

Next, the display principle of this liquid crystal device will be explained.

Light incident on the liquid crystal device through the glass substrate 802 is reflected by the dielectric mirror 807, passes back through the liquid crystal and then leaves the liquid crystal device

through the glass substrate 802. During that time, the polarization of the light is changed by the liquid crystal 805 whose orientation is controlled by an applied voltage. Application of the voltage to the matrix electrode 808 generates an electric field between the matrix electrode 808 and the counter electrode 803. This electric field changes the orientation of the liquid crystal molecules and, hence, the polarization of the light emitted from the liquid crystal device.

In this embodiment, the matrix electrode 808 is made of aluminium. In a case where an electrode made of aluminium is used, provision of a protective film is conventionally required in order to prevent occurrence of electrochemical reaction. However, provision of the protective film is not necessary in this case due to the presence of the dielectric mirror.

Furthermore, since the dielectric mirror is seamless, a uniform display state can be obtained when no voltage is applied. Even when a voltage is applied, a high-definition display, having less seams than the conventional liquid crystal device, can be obtained.

A matrix electrode 808 made of chromium may also be used. The electrode made of chromium, which cannot be conventionally used due to low reflectance, is electrochemically stable.

The dielectric mirror is formed by alternately laminating thin films of  $\text{SiO}_2$  and amorphous silicon by electron beam evaporation. The dielectric mirror has 90% or more of reflectance at the central wavelength of a predetermined wavelength region.

The oblique evaporation used for orientation of the liquid crystal is an alignment technique in which the liquid crystal is oriented using the crystals grown obliquely relative to the normal of the substrate. In the oblique evaporation conducted in this embodiment,  $\text{SiO}_2$  was evaporated on the substrate which was inclined at  $85^\circ$  relative to the normal of the substrate.

Alignment of the liquid crystal molecules by a film formed on the dielectric mirror and by a rubbing method may also be performed. In that case, the dielectric mirror must be designed with the thickness or reflectance of the orientation film taken into consideration in order to prevent reduction in the index of refraction.

This embodiment has the following advantages.

(1) Since the dielectric mirror formed on the liquid crystal driving electrode is used as a reflecting plate, it is not necessary for the reflectance of the liquid crystal driving electrode to be taken into consideration. Therefore, a wide variety of materials can be used as the material of the electrode, increasing the degree of design freedom of the liquid crystal device.

(2) Since the dielectric mirror acts as a protec-

tive film for the electrode, materials having low electrochemical stability can be used as the material for the electrode, also increasing the degree of design freedom of the device.

(3) Presence of the seamless dielectric mirror assures uniform display when no voltage is applied to the electrode and ensures high-definition display having less seams than the conventional display device when a voltage is applied.

(4) Since the reflecting film is present above the liquid crystal driving electrode, special processing of the gap between the electrodes, such as light blocking process, is not necessary.

#### Fourth Embodiment

This embodiment is characterized in that the amplitude modulation type liquid crystal device is used as means for optically addressing another liquid crystal display member, as shown in Fig. 9.

In Fig. 9, a reference numeral 900 denotes a glass substrate, 901 denotes an X-Y matrix which employs thin film transistors (TFT) as active elements, and 902 denotes a liquid crystal driven by the TFTs. The portion composed of these components is called a TFT two-dimensional image control plate. The external view, arrangement of the pixels and optical characteristics of this control plate are the same as those of the TN mode liquid crystal device used in the first embodiment.

In Fig. 9, a reference numeral 920 denotes a photoconductive layer, 921 denotes a liquid crystal layer for forming an image, and 922 denotes a transparent electrode. The portion of the optically addressed liquid crystal device is called a liquid crystal display member. In Fig. 9, the two-dimensional image control plate 910 and the liquid crystal display member 930 are shown apart from each other through the glass substrate for the ease of explanation.

The light emitted from a light source for addressing passes through the TFT type control plate 910, by which it is modulated by the unit of pixel on the basis of an input driving signal. The two-dimensional image formed by the control plate is addressed in a state in which the positional relation between the individual pixels is maintained, and thereby forms a two-dimensional image at the accurate position in the photo-conductive layer of the liquid crystal display member 930, by which a desired image is formed on the liquid crystal layer 921 of the liquid crystal display member 930.

The use of TFTs for the control of the input two-dimensional image fixes the position of the matrix on the liquid crystal layer, and eliminates a complicated optical system for addressing. This makes addressing of the photoconductive layer accurate and easier.

In this embodiment, a problem caused by the structure of the TFTs may arise. In a case when the area of the black matrix, where wiring of the TFTs is arranged, is large, the resolution of the liquid crystal display device may be decreased. In that case, the two-dimensional image projected onto the photo-sensitive layer is blurred in order to substantially eliminate the black matrix between the pixels. This makes effective use of the photo-conductive layer possible, and enables resolution of the image formed on the liquid crystal layer to be improved.

Any light source can be used for addressing as long as the light can be absorbed by the photo-conductive layer. In the case of a laser beam, diffusion of the light can be eliminated and more accurate addressing is made possible. The use of white light reduces restrictions for designing.

The liquid crystal display device of this embodiment is small in size and weight and assures a sharp image having no distortion.

#### Fifth Embodiment

In this embodiment of an optical apparatus according to the present invention, at least one active matrix is used, and a two-dimensional image is reduced in size and then projected onto the photo-conductive layer.

Fig. 10 shows the configuration of the liquid crystal device of this embodiment. In this embodiment, TFTs are used in an X-Y matrix, as in the case of the fourth embodiment. In Fig. 10, a reference numeral 900 denotes a glass substrate, 901 denotes a TFT matrix, and 902 denotes a liquid crystal driven by the TFT matrix. The portion composed of the above components is called a TFT two-dimensional image control plate 910.

In Fig. 10, a reference numeral 920 denotes a photoconductive layer, 921 denotes a liquid crystal layer for forming an image, and 922 denotes a transparent electrode. The portion composed of these components is called a liquid crystal display member 930. In this embodiment, an optical system 940 is provided between the two-dimensional image control plate and the liquid crystal display member for reduction of the image.

The light emitted from the light source for addressing passes through the TFT control plate 910, by which it is modulated by the unit of pixel on the basis of the driving signal input to the control plate to form a two-dimensional image. The two-dimensional image passes through the lens 940 which is the optical system for reduction, by which a reduced image is formed on the photo-conductive layer of the liquid crystal display member 930 in a state wherein the positional relation between the individual pixels is retained. This two-



dimensional image forms a desired image on the liquid crystal layer 921 of the liquid crystal display member.

In this embodiment, it is possible to prevent reduction in the resolution caused by the black matrix and aperture of the TFTs. For example, in a case where the same TFTs as those used in Fourth Embodiment are used and where the two-dimensional image is reduced to one half, the size of the pixel is reduced to  $40 \times 45 \mu\text{m}$  on the photoconductive layer, and the area of the black matrix is also reduced. The magnification for reduction is optional not fixed. It is thus possible to improve the resolution without blurring the image, unlike the case of Fourth Embodiment.

In this embodiment, a lens is used as the optical system for reduction. However, any means for reducing an image while maintaining the matrix can be used. Such means include an optical fiber and a lens array.

Furthermore, it is possible to obtain sharper images by using a plurality of TFT matrices. Fig. 11 shows the concept of such a system. This example uses four TFT matrices. The two-dimensional image is divided into four parts, each of which is modulated by the corresponding TFT matrix. The modulated four images are projected onto the photoconductive layer in such a manner that they form a single image. In this way, the photoconductive layer can be used effectively, and a high-density and high-resolution liquid crystal display device having a wider display area can thus be provided.

The liquid crystal device of this embodiment is small in size and weight and assures a sharp image having no distortion.

#### Sixth Embodiment

In this embodiment of an optical apparatus according to the present invention, a two-dimensional image is controlled using two active matrices placed one on top of the other so as to solve the problem involving the black matrix and aperture of the active matrix and thereby to improve the resolution of the liquid crystal device.

Fig. 12 shows the configuration of the liquid crystal display device of the sixth embodiment. In Fig. 12, a reference numeral 900 denotes a glass substrate, 901 denotes a TFT matrix which is the same as that used in the first embodiment, and 902 denotes a liquid crystal driven by the TFT matrix. The portion composed of the above components is called a TFT two-dimensional image control plate. In this embodiment, two two-dimensional image control plates are placed one on top of the other (910).

In Fig. 12, a reference numeral 920 denotes a

photoconductive layer, 921 denotes a liquid crystal layer for forming an image, and 922 denotes a transparent electrode. The portion composed of these components is called a liquid crystal display member 930.

The active devices (image control plates) are placed one besides the other with the pixels of one active device being offset from those of the other active device. That is, the active devices are placed in such a manner that the pixel portion of one of the active devices overlaps the black matrix portion of the other active device. Fig. 13 shows the positional relationship between the pixels of the two active devices. The pixels are disposed as close as possible such that they do not overlap when they are projected onto the photoconductive layer. Furthermore, since the black matrix portion must transmit light, a transparent electrode is used for wiring, and no light blocking layer is provided.

When two active devices are used, they share control of the two-dimensional image, and the black matrix portions are compensated for. Furthermore, the size of the pixels of each device can be decreased, and the area of the wiring can be assured.

The liquid crystal display apparatus of this embodiment is small in size and weight and assures provision of a sharp image having no distortion.

As will be understood from the foregoing description, since the two-dimensional image is controlled using the X-Y matrix, addressing of the photoconductive layer is simplified and made accurate. The liquid crystal display apparatus is small in size and in weight and can be formed as one unit. Since no special scanning or optical system is required in the light source for addressing, the overall size of an optical apparatus, including the liquid crystal device, a light source and a driving circuit, can also be decreased.

In a case where an image is synthesized using at least two liquid crystal devices according to the present invention, overlapping of the liquid crystal devices by the unit of pixel is possible. Overlapping of the two liquid crystal devices requires optical positioning thereof and does not require provision of a complicated position correction circuit. As a result, synthesis of colors can be facilitated, and synthesis of a high-definition image is made possible.

According to the present invention, it is possible to compensate for the black matrix of the active matrix and thereby to obtain a high-density and high-resolution image. Resolution can be increased by reducing the size of each pixel and thereby increasing the pixel density. However, to satisfy these requirements by a single active matrix is very difficult. In this invention, these requirements can be fulfilled using a readily manufactured active matrix. Furthermore, since the intensity of the writ-

ing light can be decreased to a degree which is strong enough to sensitize the photo-conductive layer, heat generation of the active matrix due to the light passing the matrix can be eliminated.

#### Seventh Embodiment

Fig. 14 shows the configuration of the liquid crystal device used in the optical apparatus according to the seventh embodiment of the present invention. A semiconductor laser 1400 is used as a coherent light source. A laser beam 1409 emitted from the semiconductor laser 1400 is enlarged and converted into parallel rays of light by means of a collimator lens 1401 and then made incident on a TN mode liquid crystal device 1402 where the beam is subjected to two-dimensional amplitude modulation. The obtained two-dimensional image is led to an ECB mode liquid crystal device 1406 which is in optically conjugate relationship with the TN mode liquid crystal device 1402 by the action of an afocal system consisting of a lens 1403, a slit 1404 and a lens 1405 and subjected to two-dimensional phase modulation. The obtained two-dimensional image is output onto an output surface 1408 as a predetermined pattern by a Fourier transform lens 1407.

Both the liquid crystal devices 1402 and 1406 are of the TFT active matrix type, and respectively have the same external appearance, pixel arrangement and optical characteristics as those of the TN mode liquid crystal device in the first embodiment and as those of the ECB mode liquid crystal device in the second embodiment.

The cascade arrangement of the TN mode liquid crystal device 1402 for amplitude modulation and the ECB mode liquid crystal device 1406 for phase modulation enables simultaneous control of the amplitude and phase of the coherent light.

When amplitude modulation is conducted by the TN mode liquid crystal device 1402, phase shift also occurs. In the TN mode liquid crystal device shown in Fig. 14, the directions of the axes of the two polarizing plates are orthogonal to each other, and the direction of the transmission of the front polarizing plate is orthogonal to the director of the liquid crystal molecules on the incident surface.

The above-described arrangement of the TN mode liquid crystal device enables phase shifts generated in the TN mode liquid crystal device 1402 to be suppressed. As a result, compensation for the phase shifts by means of the ECB mode liquid crystal device 1406 of the subsequent stage is facilitated.

To provide a cascade arrangement of the ECB mode liquid crystal device 1406 and the TN mode liquid crystal device 1402, the direction of the long axis of the liquid crystal molecules in the ECB

mode liquid crystal device 1406 must be made parallel to the direction of the transmission of the rear polarizing plate in the TN mode liquid crystal device 1402.

In this way, compensation for the aforementioned phase shifts generated in the TN mode liquid crystal device and predetermined phase modulation of the laser beam 1409 can be achieved at the same time utilizing the phase modulation effect of the ECB mode liquid crystal device 1406.

Fig. 15(a) shows amplitude distribution of the kinoform (for example, IBM J.Res. Dev. 13 (1969)-159) recorded using the amplitude/phase modulation type liquid crystal device of this embodiment. With the amplitude components of the information on an object (or an image) taken into consideration, reproduction of a sharp image having less quantization errors was possible. It was impossible to reproduce an excellent image from the kinoform recorded with the constant amplitude, as shown in Fig. 15(b).

#### Eighth Embodiment

Fig. 16 shows the configuration of the liquid crystal device of the optical apparatus according to an eighth embodiment of the present invention.

A laser beam 1611 emitted from a semiconductor laser 1600 is converted into parallel rays of light by means of a collimator lens 1601 and then made incident on a TN mode liquid crystal device 1602. At that time, the beam 1611 is linearly polarized parallel to the surface of the paper. However, the beam 1611 is subjected to amplitude modulation and the output polarization angle is rotated by 90 degrees by the TN mode liquid crystal device 1602, and the beam 1611 is thereby made incident on a polarization beam splitter 1603 as light which is polarized perpendicularly to the surface of the paper. The beam 1611 is then converted into a circularly polarized light by the action of a quarter wave plate 1604, passes through a lens 1605 and a slit 1606, and then reaches a reflecting plate 1607. The beam 1611 turns its direction and is converted into a light which is linearly polarized parallel to the surface of the paper by the action of the quarter wave plate 1604, reflected by the polarization beam splitter and is made incident on an ECB mode liquid crystal device 1608 where it is subjected to phase modulation. Finally, the beam 1611 is output onto an output surface 1610 in a desired pattern by a Fourier transform lens 1609. In order to compensate for the phase shift generated in the TN mode liquid crystal device 1602 by means of the ECB mode liquid crystal device 1608, the direction of the transmission of the rear polarizing plate in the

TN mode liquid crystal device 1602 is made orthogonal to the director of the liquid crystal molecules of the ECB mode liquid crystal device 1608.

In this embodiment, since the apparatus is constructed as a reflection type which uses the polarization beam splitter 1603, the overall size thereof can be reduced.

#### Ninth Embodiment

Fig. 17 shows the configuration of the optical apparatus according to a ninth embodiment of the present invention.

The configuration of this optical apparatus is partially the same as those of the apparatuses shown in Figs. 14 and 16, that is, the portion including a semiconductor laser 1700 for emitting a beam 1709, a collimator lens 1701, and a TN mode liquid crystal device 1702, and the portion including an ECB mode liquid crystal device 1706, a Fourier transform lens 1707 and an output surface 1708 are the same. The optical apparatus shown in Fig. 17(a) differs from those shown in Figs. 14 and 16 in that an afocal system, consisting of a pair of planar microlens arrays 1703 and 1705, is disposed between the two liquid crystal devices 1702 and 1706 to connect them. Fig. 17(b) shows in an enlarged fashion the portion of the optical apparatus including the afocal system. Two corresponding pixels of the two liquid crystal devices 1702 and 1706 are connected to each other by means of a pair of microlenses 1710. A Fourier transform surface 1704 is a focal point in image space for the planar microlens array 1703 of the preceding stage and an object focal point for the planar microlens array 1705 of the following stage. In order to compensate for the phase shifts generated in the TN mode liquid crystal device 1702, the direction of the transmission of the rear polarizing plate in the TN mode liquid crystal device 1702 is made parallel to the direction of the long axis of the liquid crystal molecules of the ECB mode liquid crystal device 1706.

In this embodiment, since the afocal system consisting of the pair of planar microlens arrays is used in the manner shown in Fig. 17, the overall size of the apparatus can further be reduced.

#### Tenth Embodiment

Fig. 18(a) shows a spherical lens recorded on an ECB mode liquid crystal device 1801 of the optical apparatus according to a tenth embodiment of the present invention. The function of the spherical lens is recorded as a Fresnel zone plate 1803 on a display area 1802 having 320x 220 pixels. The pixels are arranged in a matrix fashion on the display area 1802. The light wave modulation char-

acteristics of the liquid crystal device 1801 are shown in Fig. 6. As an applied voltage varies, the phase of the light wave which passes through the liquid crystal spatial device 1801 varies continuously from 0 to 2 $\pi$ . On the other hand, the amplitude of the light wave remains the same. These characteristics of the device are utilized when the phase type zone plate is recorded by inputting a voltage signal in such a manner that a phase corresponding to the space coordinate of a pixel is given to each pixel.

Fig. 18(b) shows how a laser beam 1800 is gathered by such a phase type zone plate. The laser beam 1800 incident on the liquid crystal device 1801 is focused in a point F<sub>1</sub> on an optical axis by the action of the phase type zone plate 1803. The focused point can be varied from point F<sub>1</sub> to point F<sub>2</sub> by changing the information input to the liquid crystal device 1801 and thereby recording the phase type zone plate having different focal length.

In this embodiment, a spherical lens is recorded on the liquid crystal device 1801. However, a cylindrical or aspherical lens may also be recorded as the phase type zone plate on the liquid crystal device. Furthermore, it is possible to perform beam scanning in a three-dimensional space by rewriting the lens function to be recorded at a high speed.

#### Eleventh Embodiment

Fig. 19(a) shows a lens array 1901 recorded on the ECB mode liquid crystal device 1801 in the optical apparatus according to an eleventh embodiment of the present invention.

The lens array 1901 consists of spherical lenses having the same focal length. The individual spherical lenses are recorded on the liquid crystal device as the phase type zone plate, as in the case of the tenth embodiment. Twelve spots having the same intensity can be obtained from a single laser beam using the lens array 1901 shown in Fig. 19(a). Fig. 19(b) shows a composite lens 1902 recorded on the liquid crystal device. The composite lens 1902 is a combination of four spherical lenses having different focal lengths. Four spots can be formed from a single laser beam at different positions from the liquid crystal device using such a composite lens 1902.

In this embodiment, since the function of a plurality of lenses are not overlapped, the lens functions can be recorded in the form of phase distribution. In this embodiment, a plurality of spherical lenses are recorded on the liquid crystal device. However, a combination of cylindrical or aspherical lenses may also be recorded.

## Twelfth Embodiment

Fig. 20(a) shows a composite lens recorded on the liquid crystal device in the optical apparatus according to a twelfth embodiment of the present invention. The composite lens consists of two spherical lenses having different focal lengths and are recorded on the liquid crystal device in such a manner that at least parts thereof overlap. Let the functions of lenses 2001 and 2002 respectively be  $\phi A$  and  $\phi B$ , the function of the composite lens to be recorded on the liquid crystal device is given by:

$$1/2 \{ \exp(\phi A) + \exp(\phi B) \}.$$

This is a complex function whose value varies continuously from 0 to 1. To record such a function, a liquid crystal device capable of controlling the amplitude and phase of a light wave independently and simultaneously is required. Hence, the liquid crystal device includes an ECB mode liquid crystal device 2003 capable of phase modulation and a TN mode liquid crystal device 2006 capable of amplitude modulation. These two types of liquid crystal devices are connected in a conjugate relation with a pair of planar microlens arrays therebetween, as shown in Fig. 20(c). The light wave modulation characteristics of the ECB mode and TN mode liquid crystal devices are respectively shown in Figs. 6 and 5.

A laser beam 2000 is first made incident on the TN mode liquid crystal device 2003 and is subjected to amplitude modulation. The liquid crystal device 2003 is optically arranged such that the two polarizers are crossed nicols and such that the direction of transmission of the front polarizer is orthogonal to the director of the liquid crystal molecules on the incident side. This arrangement of the liquid crystal device enables phase changes of a light wave to be reduced to a level that can be practically ignored. Next, the laser beam passes through the pair of flat plate microlens arrays 2004 and 2004 disposed in an afocal fashion and is led to the ECB mode liquid crystal device 2006 where it is subjected to phase modulation. As a result, laser beam spots are obtained at two points  $F_1$  and  $F_2$  from a single laser beam. This formation of the two beam spots is shown in Fig. 20(b). In this embodiment, a composite lens consisting of two spherical lenses is used. However, the number of lenses recorded in an overlapping fashion can be increased. The configurations shown in Fig. 16 and 17 may be used as the amplitude phase simultaneous modulation type liquid crystal device shown in Fig. 20.

## Thirteenth Embodiment

Fig. 21 shows the configuration of the optical apparatus according to a thirteenth embodiment of the present invention.

A laser beam 2107 emitted from a laser light source 2101 is enlarged into parallel rays of light by a collimator lens 2102, and then made incident on a liquid crystal device 2103. At the liquid crystal device 2103, the wave front of the laser beam is modulated by the action of a computer-generated hologram recorded on the liquid crystal device. Thereafter, the laser beam passes through a lens 2105 and then forms a wiring pattern 2108 on a light-receiving portion 2109 on an electric circuit element 2106. The light-receiving portion 2109 is made of a photo-sensitive material (amorphous silicon) whose electric conductivity changes in accordance with the irradiation of a laser beam and thereby forms the wiring of an electric circuit. When irradiation of the laser beam stops, the wiring disappears.

Data of the hologram pattern created by the computer beforehand are stored in a pattern generator 2104 for recording the hologram on the liquid crystal device 2103 so that various patterns can be instantaneously generated.

The computer-generated hologram used in this embodiment is the phase modulation type Fourier transform hologram in which the pixels and the Fourier transform values (phase component) have a one-to-one correspondence.

In this way, it is possible to utilize a limited number of pixels effectively when the computer-generated hologram is recorded on the liquid crystal device and to utilize light substantially 100 percent when the wiring pattern is reproduced from the hologram.

The liquid crystal device shown in Fig. 21 is an ECB mode liquid crystal device with a TFT provided at each pixel as an active element. The optical characteristics of the liquid crystal device are the same as those of the liquid crystal device used in the second embodiment. The use of such a liquid crystal device enables a wiring pattern having a desired intensity pattern to be freely generated.

Fig. 22 shows examples of the wiring pattern. Fig. 22(a) shows a basic form of connection of an input/output terminal 2201 by means of a wiring pattern 2203 recorded on a photo-sensitive material 2202. Fig. 22(b) shows an example of connection by means of a plurality of wires. Fig. 22(c) shows an example of a directional coupler in a light circuit. Fig. 22(d) shows an example of wiring of a device in which a plurality of photo-sensitive materials 2202 are connected by an optical or electric circuit 2211.

As will be clear from the foregoing description, it is possible to provide an optical coupling appara-

tus capable of utilizing light of the coherent light source effectively by the action of the phase modulation type computer-generated hologram recorded on the liquid crystal device. Furthermore, if a wavelength-variable laser is used, wiring pitch errors can be corrected only by changing the wavelength. Furthermore, since the hologram is used, breaking or short-circuiting of the pattern does not occur easily, which would otherwise occur due to the dust on the mask surface.

The optical apparatus of this embodiment can be applied to an optical switch or optical information processing apparatus.

#### Fourteenth Embodiment

Fig. 23 shows the configuration of the optical apparatus of this embodiment.

In this embodiment, an optical circuit device 2308 made of an photo-sensitive material is used in place of the electric circuit device used in the thirteenth embodiment. An electro-optic crystal material ( $\text{Bi}_{12}\text{SiO}_{20}$  is used in this embodiment) whose refractive index varies by light is used as the photo-sensitive material. The wiring pattern recorded is erased by the irradiation of a laser beam having a wavelength different from that of the laser beam used for recording. In the structure shown in Fig. 23, laser beams 2306 and 2307 having different wavelengths are joined by a dichroic prism 2303 such that they have a common optical axis. Operation of the two lasers is controlled by a signal from the pattern generator 2104.

In this embodiment, a plurality of laser light sources are used for writing a pattern on or erasing the pattern from the optical circuit device. Wavelength-variable lasers may also be used.

#### Fifteenth Embodiment

Fig. 24 shows the configuration of the optical apparatus of this embodiment.

A laser beam 2412 emitted from a laser light source 2401 is enlarged into parallel rays of light by means of a beam expander 2402 and a collimator lens 2403. Thereafter, the laser beam is phase modulated by the computer-generated hologram recorded on an ECB mode liquid crystal device 2404 and the modulated laser beam reproduces the cross-sectional image of a desired body on the surface of a resin tank 2405. A resin 2406 at the surface of the resin tank which is not yet set sets by the irradiation of the laser beam. A formed model 2407 is fixed to a table 2408. An unset resin layer is set in the form of a cross-section to form a solid model as it appears on the surface of the resin tank in sequence by the downward feeding of the table 2408 by means of a Z-direction feeding

device 2409.

The ECB mode liquid crystal device is driven by a driving system 2410 connected to a computer 2411 which computes the phase type hologram by performing Fresnel transformation on the cross-sectional image of the solid model. The driving device sends a driving signal to the ECB mode liquid crystal device on the basis of the hologram data. Since the hologram has the lens function, it is not necessary to provide a lens between the ECB liquid crystal device and the resin tank.

The ECB mode liquid crystal device used in this embodiment is of the active-matrix type in which a TFT device is provided for each pixel. The external appearance, pixel arrangement, and optical characteristics of the liquid crystal device are the same as those of the liquid crystal device used in the second embodiment.

In this embodiment, since a single image is formed at one operation, the time required for the formation of the image is shorter than that required in the conventional method in which a laser beam is scanned two-dimensionally. Furthermore, since a cross-sectional image is generated utilizing the phase type hologram, light can be utilized more effectively as compared with the case in which an amplitude type light blocking mask is used. This reduces the time required for setting the resin.

#### Sixteenth Embodiment

Fig. 25 shows the configuration of the optical apparatus of this embodiment.

In this embodiment, the position at which the cross-sectional image is formed can be freely changed by changing the focal length of the lens for recording the phase type hologram. The provision of the Z-direction feeding device is eliminated and the apparatus is thereby simplified by utilizing the above-described property. As in the case of the fifteenth embodiment, the parallel rays of light are phase modulated by the computer-generated hologram recorded on the ECB liquid crystal device, and the modulated laser beam reproduces the cross-sectional image of a desired body in the resin tank. A solid model is obtained by reproducing the cross-sectional images while recording the phase type holograms having different focal lengths on the liquid crystal device in sequence.

#### Seventeenth Embodiment

This embodiment is characterized in that an amplitude/phase simultaneous modulation type liquid crystal device is used in place of the ECB mode liquid crystal device used in the sixteenth embodiment. The amplitude/phase simultaneous modulation type liquid crystal device has any of the

configurations shown in Fig. 14, 16 or 17. Since these configurations have respectively been described in the seventh, eight and ninth embodiments, description thereof is omitted.

The use of this amplitude/phase simultaneous modulation type liquid crystal device permits a substantially complete wave front control. Therefore, a surface image of a solid body can be reproduced directly in the resin tank by recording on the amplitude/phase simultaneous modulation type liquid crystal device an optically transformed image of a surface configuration calculated by means of a computer and then by irradiating a laser beam onto such an amplitude/phase simultaneous modulation type liquid crystal device. In this embodiment, the surface of a solid is set starting from the portion thereof which is shaded by the object. Thereafter, the formed article is taken out of the resin tank, and the article is irradiated with strong light to set the interior thereof.

#### Eighteenth Embodiment

Fig. 26 shows the configuration of the optical apparatus of this embodiment. In this embodiment, a plurality of optical apparatuses used in the seventeenth embodiment are disposed around the resin tank in order to increase the forming speed and to enable formation of a complicated configuration. In this embodiment, setting of the surface 2701 of a solid having a non-connected cross-section 2703, such as that shown in Fig. 27, in one operation is possible. As a result, formation of a solid substantially on a real-time basis is made possible. Furthermore, a complicated configuration that cannot be set in one operation can be formed without delay by rewriting data on the liquid crystal device.

Since the optical system according to the present invention which employs the liquid crystal device is capable of generating a light spot at a given point in space, it can be applied to the conventional method in which scanning of a laser beam is conducted.

#### Nineteenth Embodiment

Fig. 28 shows the configuration of the optical apparatus of this embodiment. In this embodiment, a TN mode liquid crystal device 2803 is disposed in an object wave path 2801, and an ECB mode liquid crystal device 2804 is disposed in a reference wave path 2802. The TN mode liquid crystal device 2803 displays an image to be recorded in black and white by utilizing the amplitude modulation characteristics thereof. The ECB mode liquid crystal device 2804 gives a predetermined phase distribution on the reference wave front and thereby performs encoding of the reference wave front

by utilizing the phase modulation characteristics. A necessary image is recorded on an electro-optic crystal 2805 over the image recorded by the TN mode liquid crystal device using the reference wave front encoded for each pixel.

Both the liquid crystal devices 2803 and 2804 are of the TFT active-matrix drive type. The external appearance, pixel arrangement and optical characteristics of these liquid crystal devices are respectively the same as those of the TN mode liquid crystal device used in the first embodiment and as those of the ECB mode liquid crystal device used in the second embodiment.

In this embodiment, since the reference wave front is encoded using the liquid crystal device, the recording density of the hologram can be increased by two orders of magnitude. The use of various types of non-linear optical materials enables reproduction of data on a real-time basis.

The recording apparatus of this embodiment can be applied to a programmable optical interconnection, a large-capacity optical storage apparatus or a three-dimensional display apparatus.

#### Twentieth Embodiment

Fig. 29 shows the configuration of the optical apparatus of this embodiment. This embodiment differs from the nineteenth embodiment in that image information is recorded as an image hologram. The image displayed on the TN mode liquid crystal device 2803 is formed in the vicinity of the electro-optic crystal 2805 by means of a lens 2901. By recording the hologram as, for example, a real image 2902, as shown in Fig. 29, a desired optical pattern can be reproduced at a desired position.

#### Twenty-First Embodiment

Fig. 30 shows the configuration of the optical apparatus of this embodiment. This embodiment differs from the nineteenth and twentieth embodiments in that image information is recorded as a Fourier transform hologram.

In this embodiment, the image displayed by the amplitude/phase simultaneous modulation type liquid crystal device 3001 is Fourier transformed by a lens 3002. At that time, a random phase distribution is placed over an image to be recorded in the liquid crystal device 3001 so that the intensity of the Fourier transform image is substantially uniform in the hologram area. A spatial filter 3003 is adapted to remove diffraction image having a high order caused by the periodic pixel arrangement of the liquid crystal device 3001.

The amplitude/phase simultaneous modulation type liquid crystal device shown in Fig. 30 has the same configuration as that shown in Fig. 14, 16 or

17. Since those configurations have respectively been described in the seventh, eight and ninth embodiments, description thereof is omitted.

Since a large number of dot-shaped holograms, on which a plurality of images are multiplexed, are disposed on the electro-optic crystal, as shown in Fig. 30, the recording density is greatly increased. This enables provision of a large-capacity optical storage apparatus.

#### Twenty-Second Embodiment

Fig. 31 shows the configuration of the optical apparatus of this embodiment.

A light emitted from a semiconductor laser 3101 is enlarged into parallel rays of light by means of a collimator lens 3102. The resultant light illuminates an electrically addressable type TN mode liquid crystal device 3103 which is displaying a pattern input thereto through a video camera 3110 and an interface circuit 3109. A first lens 3104 forms a Fourier transform pattern of the input pattern on an optically addressed ECB mode liquid crystal device 3106 in which only the phase component of the Fourier transform pattern of the reference pattern is recorded in the form of an optical correlation filter.

The external appearance, pixel arrangement and optical characteristics of the TN mode liquid crystal device shown in Fig. 31 are the same as those of the TN mode liquid crystal device used in the first embodiment. In the TN mode liquid crystal device shown in Fig. 31, the directions of the axes of the two polarizing plates are perpendicular to each other, and the direction of transmission of the front polarizing plate is perpendicular to the director of the liquid crystal molecules on the light incident surface, as in the case of the TN mode liquid crystal device used in the first embodiment.

The above-described arrangement of the TN mode liquid crystal device 3103 enables the level of phase distortion generated in the TN mode liquid crystal device 3103 to be reduced. As a result, correction of the phase distortion in the ECB mode liquid crystal device 3106 can be facilitated, and a correlation signal having a high S/N ratio can thus be obtained.

The phase modulation characteristics of the ECB mode liquid crystal device 3106 shown in Fig. 31 are shown in Fig. 6. The liquid crystal device 3106 has a homogeneous structure in which the liquid crystal molecules are homogeneously oriented relative to the liquid crystal panel at the initial stage. The liquid crystal device 3106 is arranged such that a linear phase shift of 21 or more can be obtained relative to the changes in the intensity of writing light. The liquid crystal device 3106 is formed on the slanting surface of a rectangular

equilateral prism 3105 made of a transparent material. The direction of the director of the liquid crystal molecules is parallel to the direction of transmission of the rear polarizing plate of the TN mode liquid crystal device 3103 and to the side of the light incident and emitting surface of the rectangular prism 3105.

An optical correlation filter for the phase distribution can be provided by writing a desired pattern on the optically addressed ECB mode liquid crystal device 3106 in the form of a light intensity distribution by means of a CRT or a laser scanner.

At that time, correction is made on the light intensity distribution written on the liquid crystal device 3106 so that the aforementioned phase distortion generated in the TN mode liquid crystal device 3103 and the aberration of the liquid crystal panel (the curve of the interference fringes shown in Fig. 32) can be reduced to a level that can be practically neglected.

In this embodiment, since the optical correlation filter is recorded on the optically addressed liquid crystal device capable of phase control, the task and time required for manufacturing and exchanging a filter can be eliminated, and the image processing on a real-time basis is enabled.

#### Twenty-Third Embodiment

Fig. 33 shows the configuration of the optical apparatus according to this embodiment of the present invention.

In this embodiment, a pattern is recorded on an electrically addressed TN mode liquid crystal device 3103, and an optical correlation filter is recorded on an optically addressable ECB mode liquid crystal device 3302. The liquid crystal device 3302 has a quarter wave plate between a liquid crystal layer having the homogeneous structure and a dielectric mirror, and thereby rotates the direction of polarization of an incident linearly polarized light by 90°. A combination of the liquid crystal device 3302 and a polarization beam splitter 3301 provides a compact optical system having a common optical path.

According to the present invention, since desired light wave modulation characteristics are recorded on the liquid crystal device, a general-purpose optical apparatus having a programmable light wave front control function can be provided.

The optical apparatus according to the present invention can be extensively applied to an active optical control, such as a beam steering or an optical interconnection, information processing, instrumentation, a solid forming, and a three-dimensional image display.

#### Claims

1. An optical apparatus for controlling a wave front of a coherent light, comprising at least:  
a coherent light source;  
an electrically addressed liquid crystal device having a plurality of pixels; and  
a signal generator for recording a complex amplitude distribution on said liquid crystal device. 5
2. The optical apparatus according to claim 1, wherein said signal generator includes at least a CPU, a memory circuit for storing a plurality of complex amplitude distribution data, and an interface circuit for transferring a signal from said memory circuit to said liquid crystal device. 10
3. The optical apparatus according to either of claims 1 and 2, wherein said liquid crystal device is of the matrix-drive type. 15
4. The optical apparatus according to either of claims 1 to 3, wherein said liquid crystal device includes a TN (twisted nematic) mode liquid crystal panel, and two polarizing plates respectively disposed in front and at the back of said liquid crystal panel in such a manner that directions of the axes thereof are orthogonal to each other, the direction of transmission of the front polarizing plate being orthogonal to a director of liquid crystal molecules on an incident surface. 20
5. The optical apparatus according to either of claims 1 to 3, wherein said liquid crystal device includes an ECB (electrically controlled birefringence) mode liquid crystal panel, and a single polarizing plate disposed in front of said liquid crystal panel, the direction of transmission of said polarizing plate being parallel to a plane made by the normal on said liquid crystal panel and a director of the liquid crystal molecules. 25
6. The optical apparatus according to either of claims 1 to 5, wherein said liquid crystal device includes a high-transmission substrate, a high-reflectivity substrate, a liquid crystal disposed between said high-transmission substrate and said high-reflectivity substrate, a plurality of separate electrodes disposed on at least one side of the liquid crystal, and a dielectric mirror disposed between the electrodes disposed on the side of said high-reflectivity substrate and said liquid crystal. 30
7. The optical apparatus according to either of claims 2 to 6, wherein said liquid crystal device displays a two-dimensional image by matrix control which is to be projected to another liquid crystal display member having a liquid crystal layer and a photo-conductive layer from the side of said photo-conductive layer to form an image on said liquid crystal layer. 35
8. An optical apparatus according to claim 1, including an amplitude modulation type liquid crystal device and a phase modulation type liquid crystal device. 40
9. The optical apparatus according to claim 8, wherein said amplitude modulation type liquid crystal device comprises a TN (twisted nematic) mode liquid crystal device while said phase modulation type liquid crystal device comprises an ECB (electrically controlled birefringence) mode liquid crystal device. 45
10. The optical apparatus according to claim 9, further comprising an afocal system disposed between said TN mode and ECB mode liquid crystal devices, said afocal system consisting of at least two lenses, and a slit disposed between the front and rear lens groups of said afocal system, said two liquid crystal devices being disposed in conjugate relation with each other in said afocal system. 50
11. The optical apparatus according to claim 9, further comprising an afocal system disposed between said TN mode and ECB mode liquid crystal devices, said afocal system consisting of a pair of planar microlens arrays, said two liquid crystal devices being disposed in conjugate relation with each other in said afocal system. 55
12. The optical apparatus according to claim 9, further comprising a polarization beam splitter, a quarter wave plate, a lens, a slit and a reflecting plate which components are disposed between said TN mode and ECB mode liquid crystal devices.
13. The optical apparatus according to either of claims 10 and 11, wherein the direction of transmission of a rear polarizing plate in said TN mode liquid crystal device is in a plane made by a director of liquid crystal molecules and the normal on a substrate of said ECB mode liquid crystal device.
14. The optical apparatus according to claim 12, wherein the direction of transmission of a rear polarizing plate of said TN mode liquid crystal



device is orthogonal to a plane made by a director of liquid crystal molecules and the normal on a substrate in said ECB mode liquid crystal device.

15. The optical apparatus according to either of claims 1 to 14, wherein said liquid crystal device displays a lens function in the form of a complex amplitude distribution.
16. The optical apparatus according to claim 15, wherein said liquid crystal device displays a plurality of lens functions in such a manner that they do not overlap.
17. The optical apparatus according to claim 15, wherein said liquid crystal device displays a plurality of lens transfer functions in such a manner that they are partially overlapped.
18. The optical apparatus according to either of claims 1 to 14, including a signal generator for recording a hologram on said liquid crystal device, an element made of a photo-sensitive material, said element having a plurality of input/output terminals, and a coherent light source for illuminating said hologram to reproduce an image on said photo-sensitive material.
19. The optical apparatus according to claim 18, wherein said photo-sensitive material utilizes local changes in its refractive index.
20. The optical apparatus according to claim 18, wherein said photo-sensitive material utilizes local changes its electrical conductivity.
21. The optical apparatus according to either of claims 19 and 20, wherein said coherent light source comprises at least two sources of coherent lights having different wavelengths.
22. The optical apparatus according to either of claims 1 to 14, including a signal generator for recording a hologram on said liquid crystal device, an optically setting material, and a coherent light source for illuminating said hologram to reproduce an image on said optically setting material.
23. The optical apparatus according to claim 1, including a two wave interference means, an optically recording medium, and at least one liquid crystal device disposed in either of a reference wave path or an object wave path.
24. The optical apparatus according to claim 23,

wherein said at least one liquid crystal device comprises a phase modulation type liquid crystal device disposed in said reference wave path, and an amplitude modulation type liquid crystal device disposed in said object wave path.

25. The optical apparatus according to claim 23, wherein said at least one liquid crystal device comprises a phase modulation type liquid crystal device disposed in said reference wave path, and an amplitude/phase simultaneous modulation type liquid crystal device disposed in said object wave path.
26. The optical apparatus according to either of claims 23 to 25, wherein said optical recording medium comprises an electro-optic material.
27. An optical apparatus according to claim 1, including an amplitude modulation type liquid crystal device for displaying an input image, a first lens whose front focal surface is located on the surface on which said amplitude modulation type liquid crystal device is disposed, a phase modulation type liquid crystal device disposed on a rear focal surface of said first lens, and a second lens whose front focal surface is the rear focal surface of said first lens.
28. The optical apparatus according to claim 27, wherein said amplitude modulation type liquid crystal device comprises an electrically addressed TN (twisted nematic) mode liquid crystal device while said phase modulation type liquid crystal device comprises an optically addressed ECB (electrically controlled birefringence) mode liquid crystal device, the direction of transmission of a beam polarizer in said TN mode liquid crystal device being parallel to the direction of a director of liquid crystal molecules in said ECB mode liquid crystal device.
29. The optical apparatus according to claim 28, wherein said optically addressed ECB mode liquid crystal device is disposed on a slanting surface of a 90° rectangular equilateral prism made of a transparent material, the direction of the director of the liquid crystal molecules of said ECB mode liquid crystal device being, parallel to a common side of input and output surfaces of said 90° rectangular equilateral prism.
30. The optical apparatus according to claim 28, wherein said optically addressed ECB mode liquid crystal device includes a liquid crystal

layer, a dielectric mirror, and a phase plate disposed between said liquid crystal layer and said dielectric mirror.

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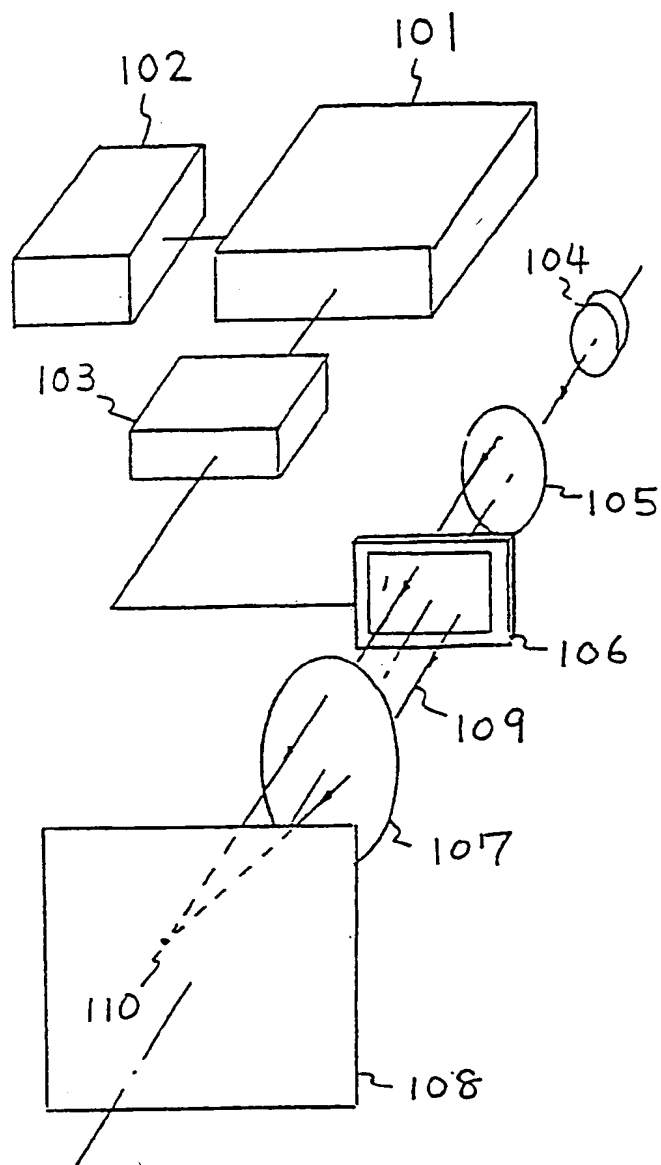


FIG. 1

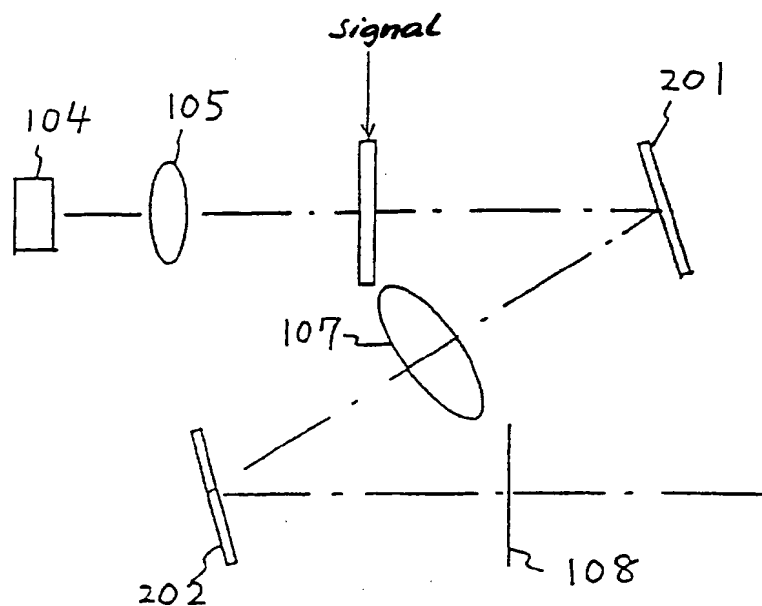


FIG. 2(a)

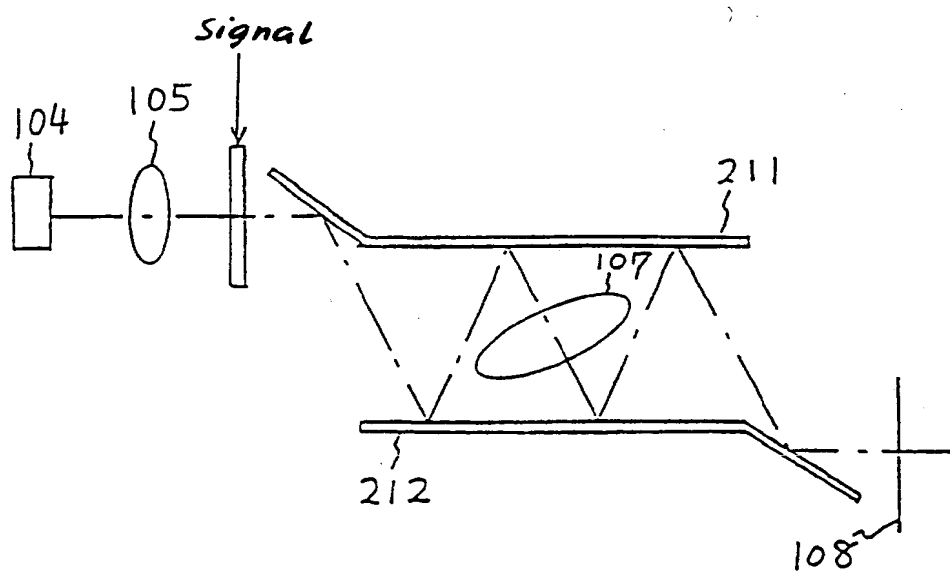


FIG. 2(b)

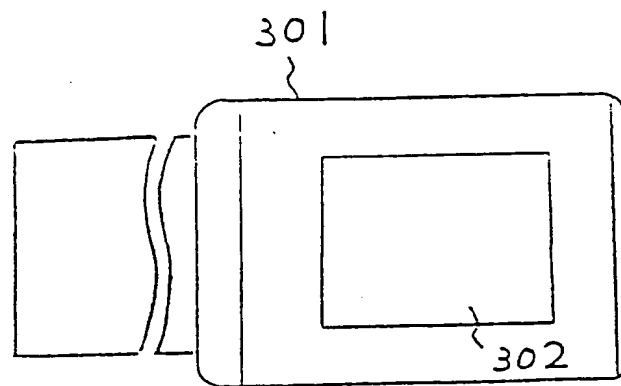


FIG. 3(a)

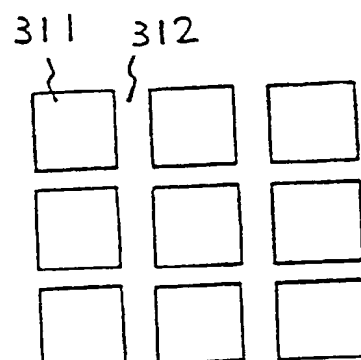


FIG. 3(b)

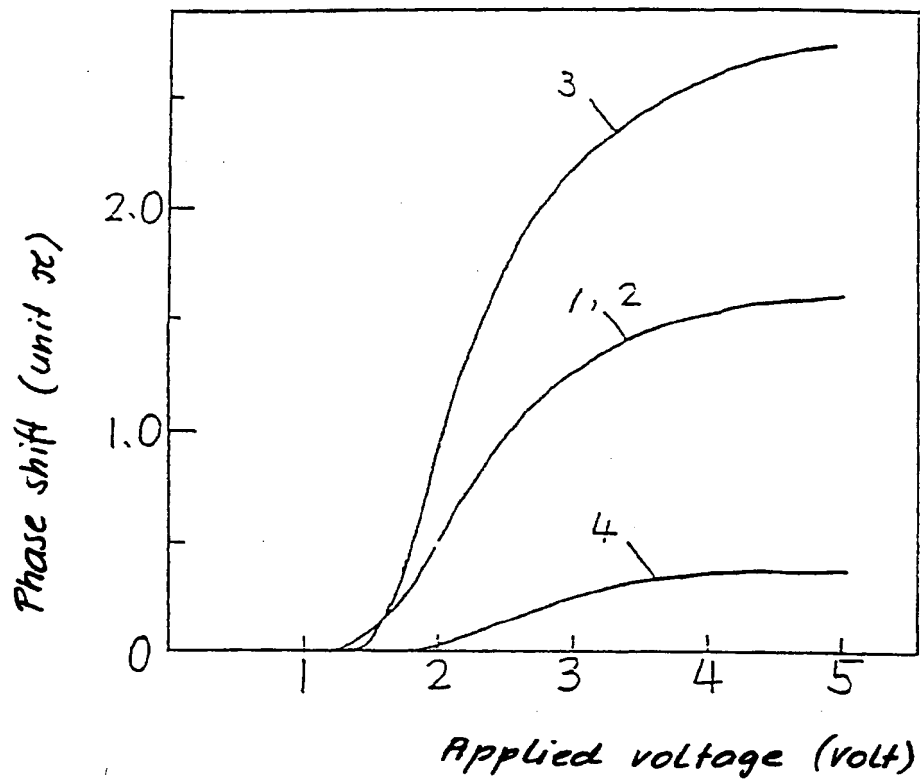


FIG. 4

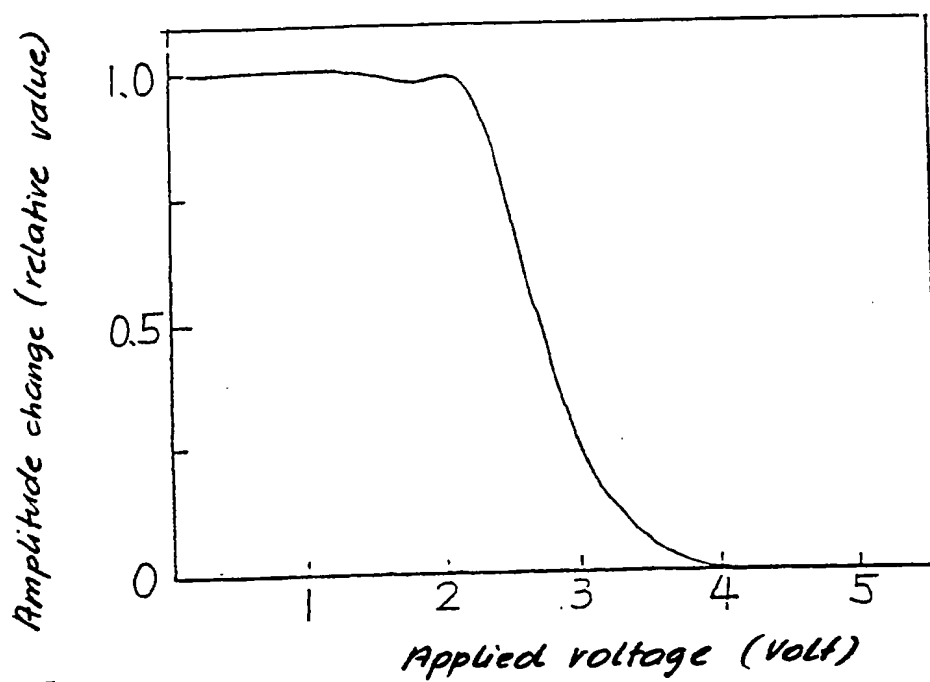


FIG. 5

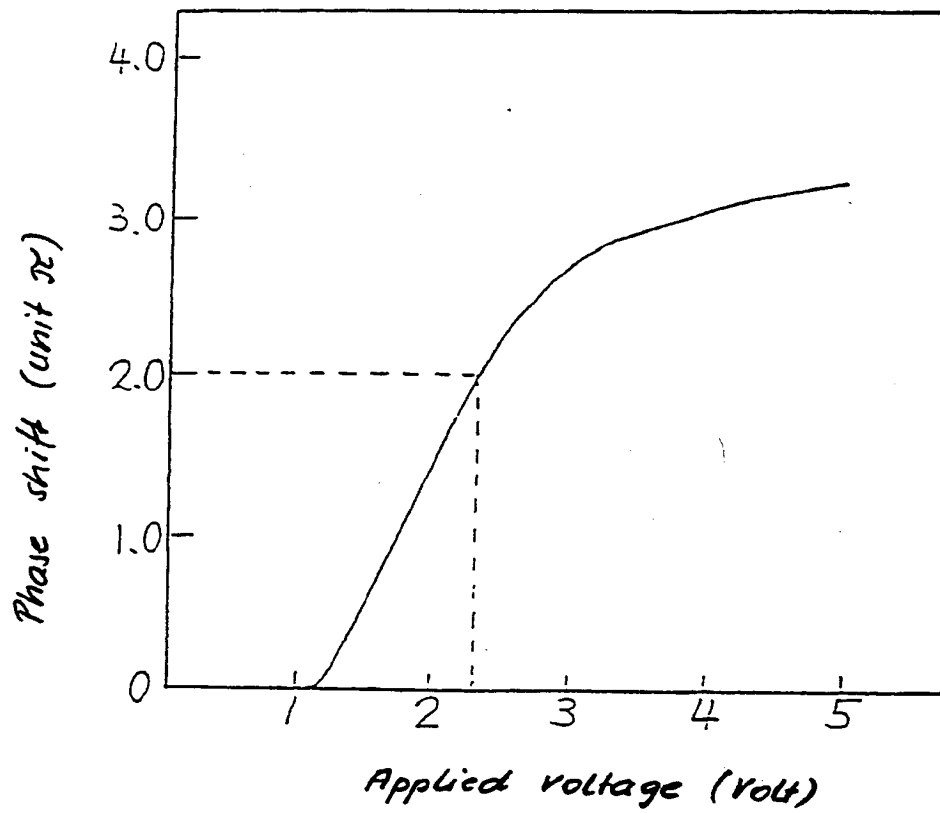


FIG. 6



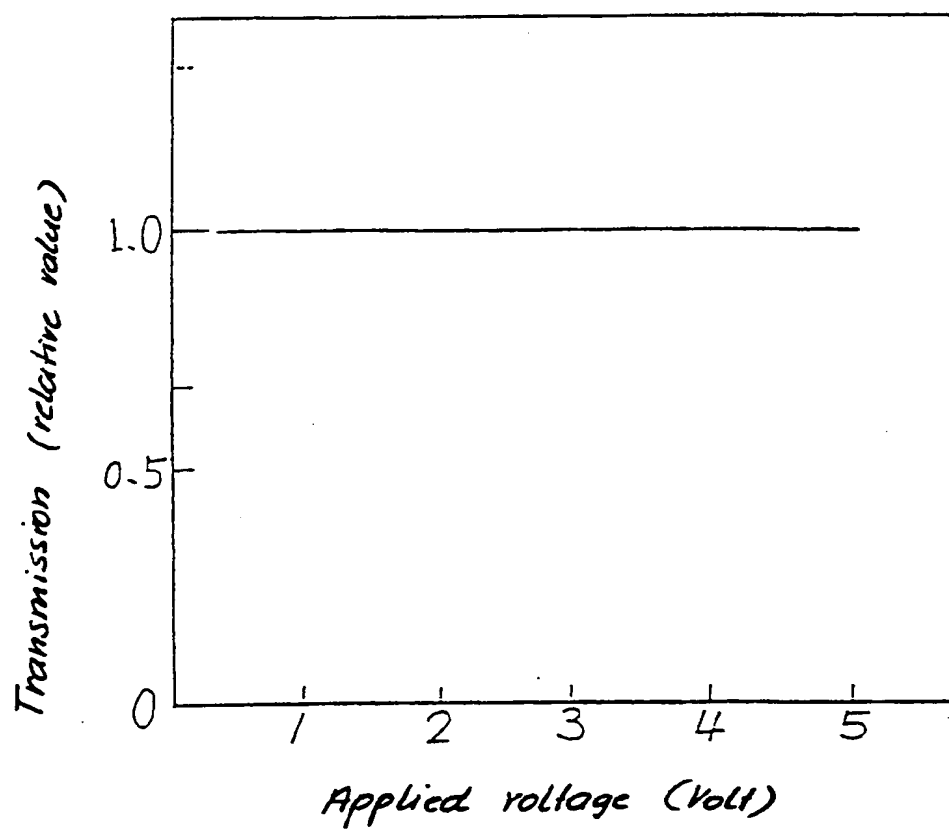


FIG. 7

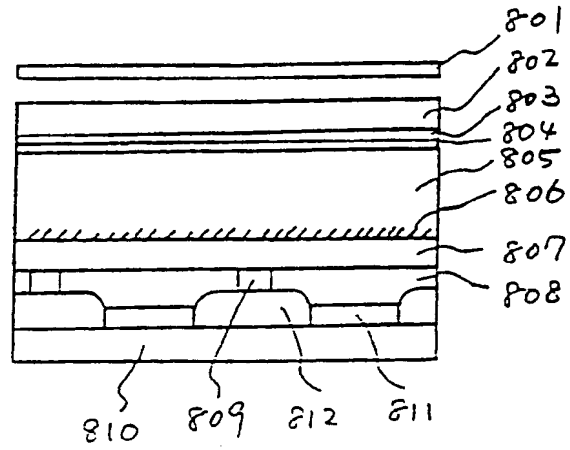


FIG. 8

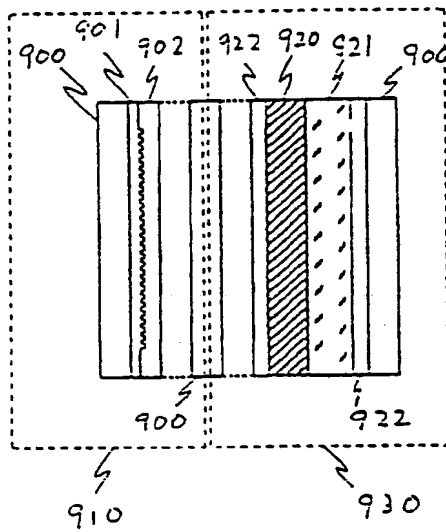


FIG. 9

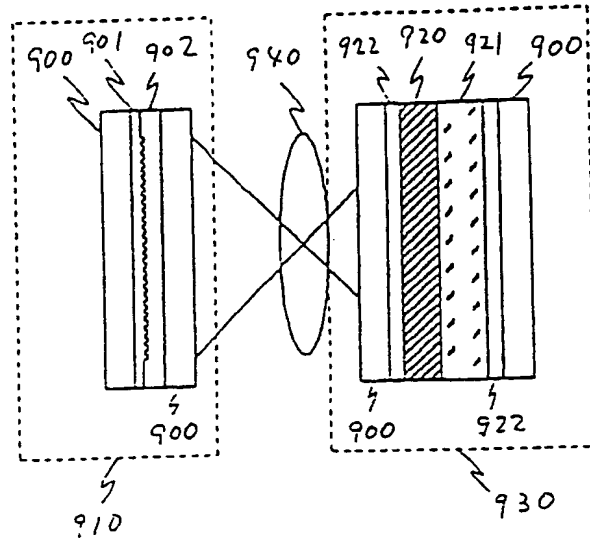


FIG. 10

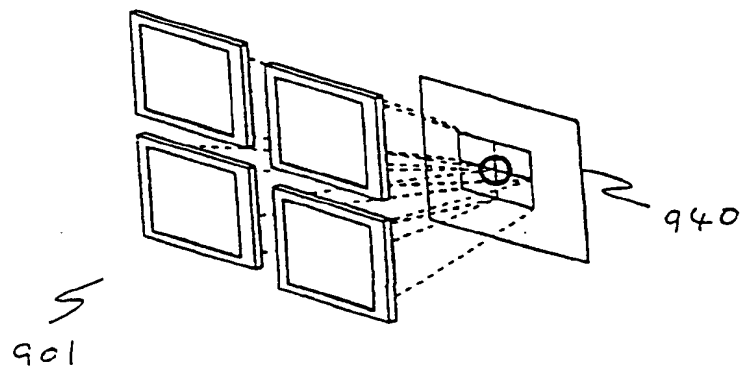


FIG. 11

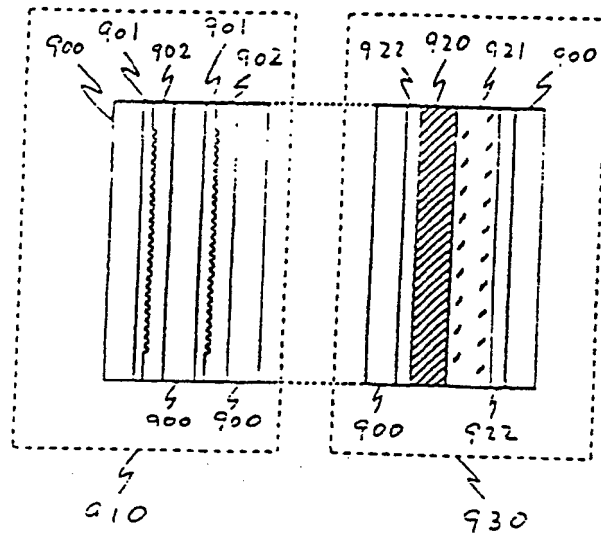


FIG. 12

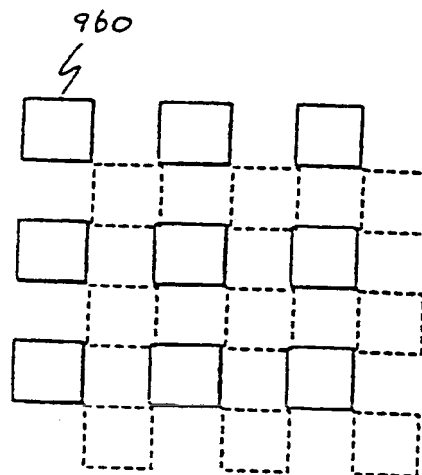


FIG. 13

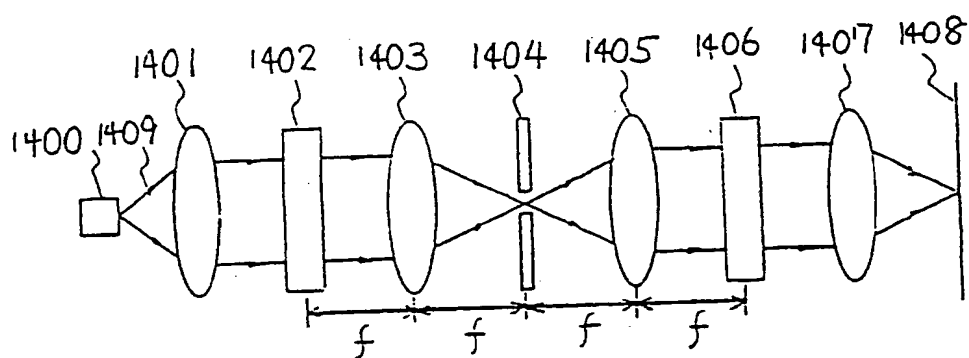


FIG. 14

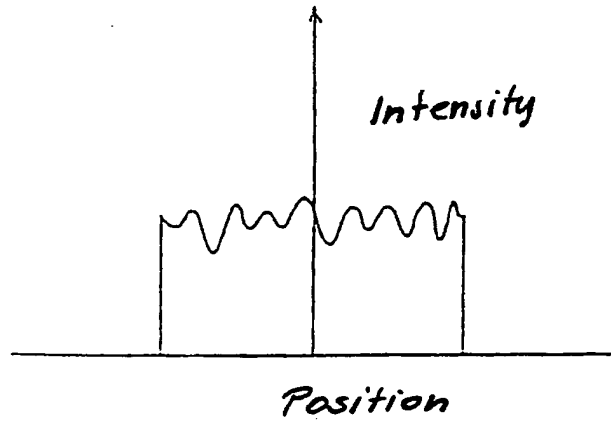


FIG. 15 (a)

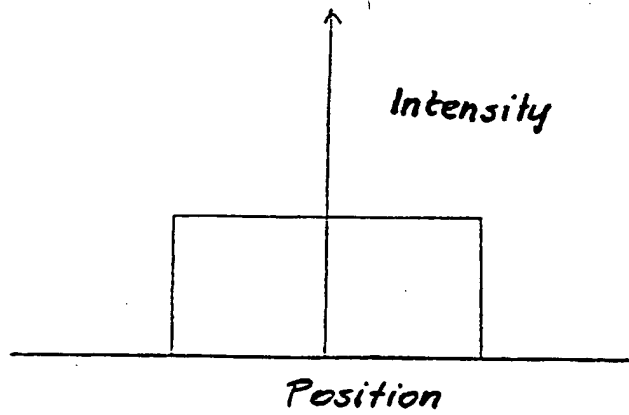


FIG. 15 (b)

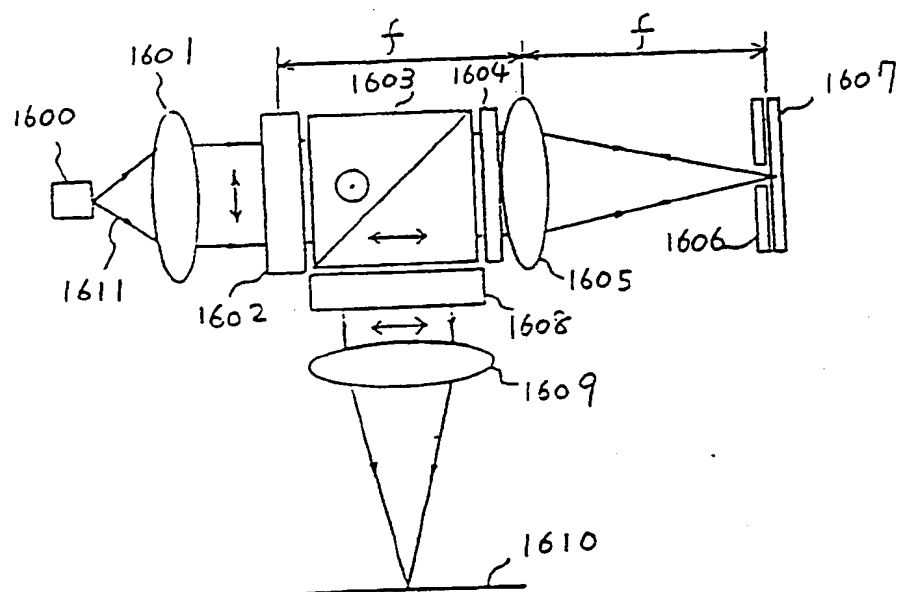


FIG. 16

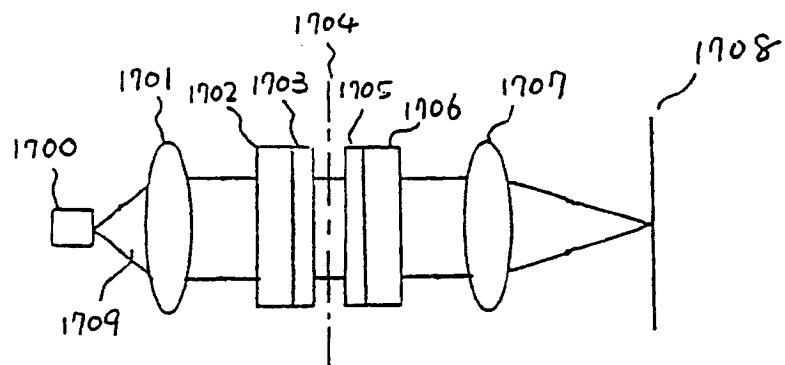


FIG. 17(a)

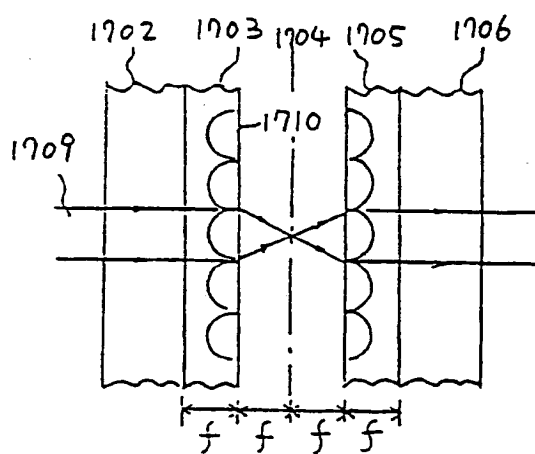


FIG. 17(b)



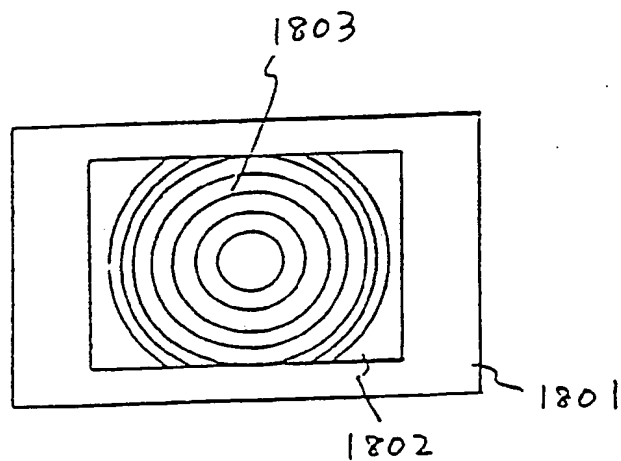


FIG. 18 (a)

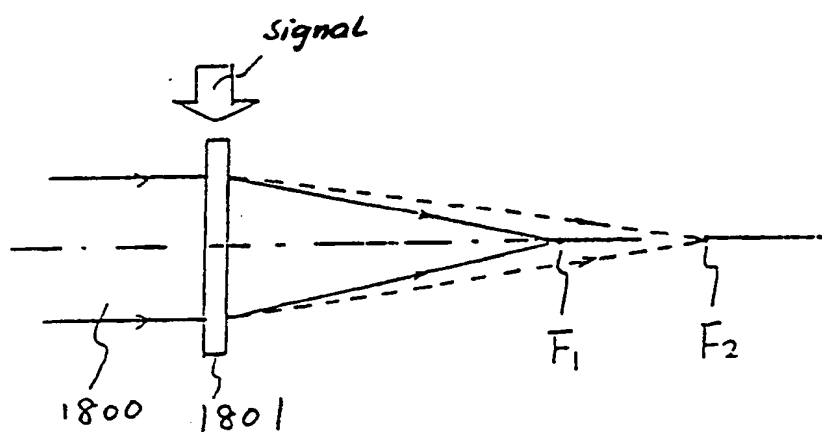


FIG. 18 (b)

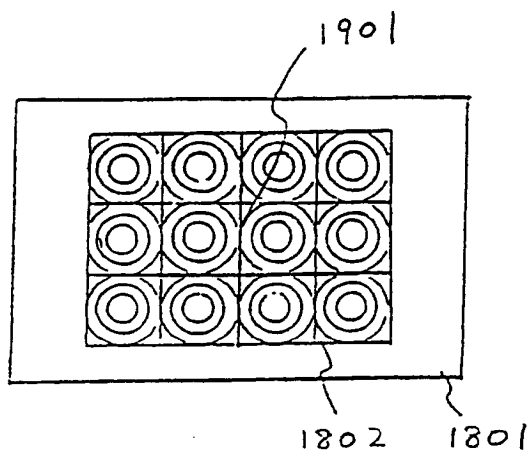


FIG. 19(a)

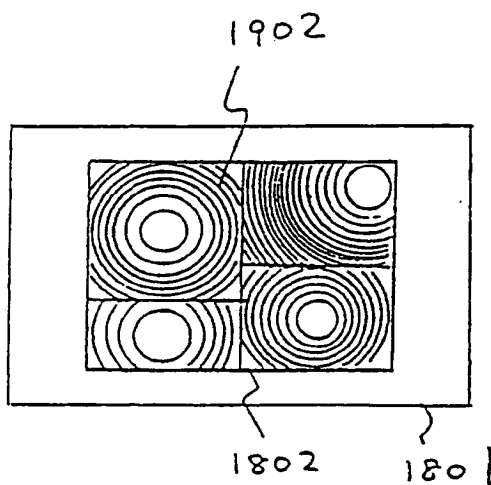


FIG. 19(b)

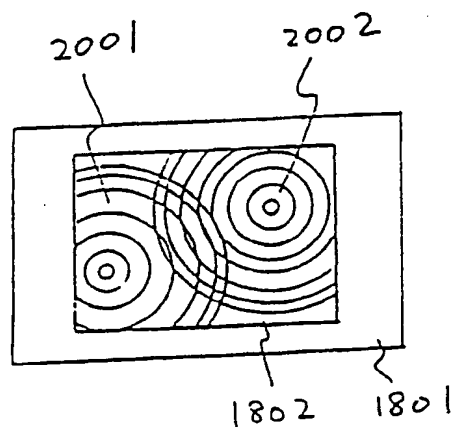


FIG. 20 (a)

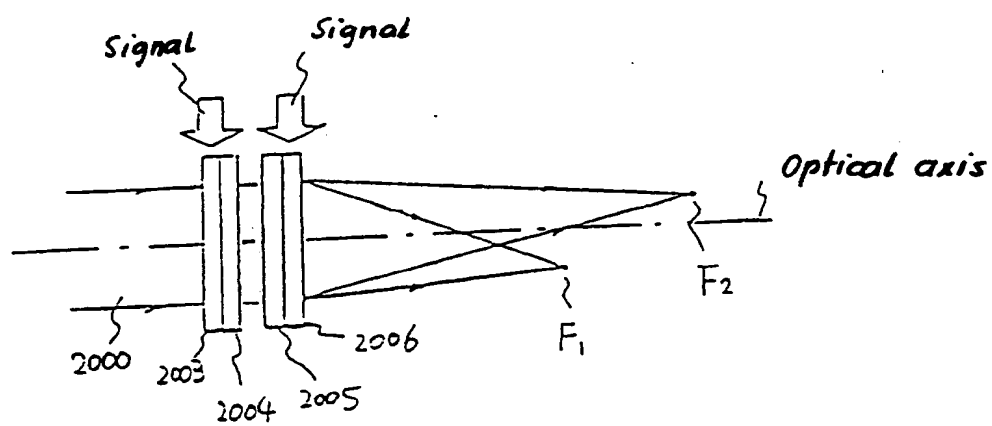


FIG. 20 (b)

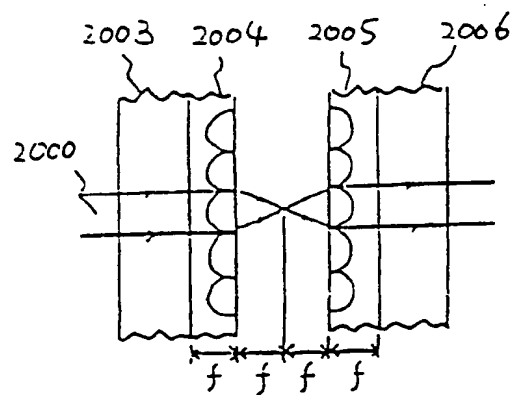


FIG. 20 (c)

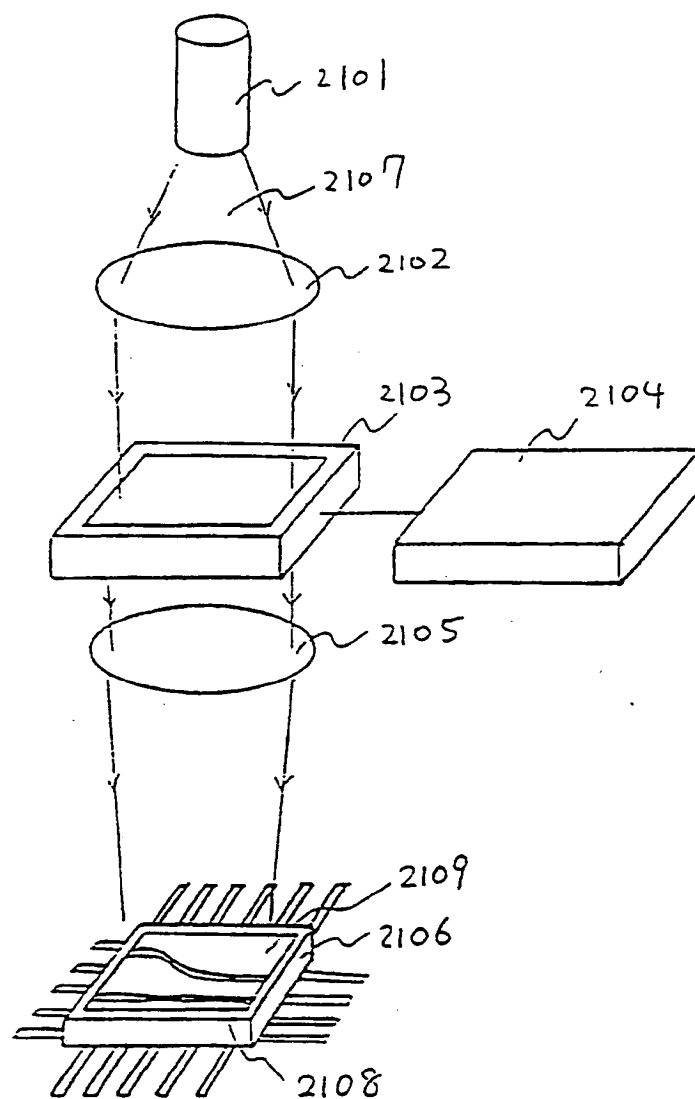


FIG. 21

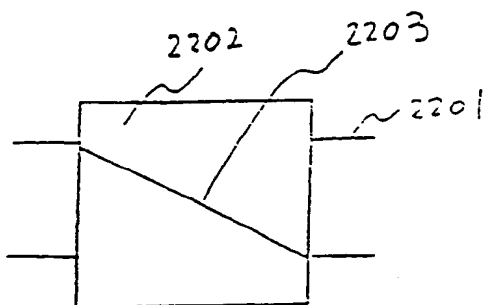


FIG. 22 (a)

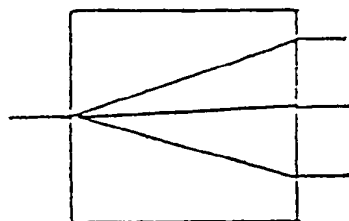


FIG. 22 (b)

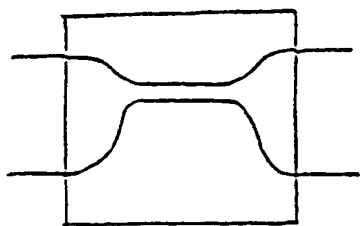


FIG. 22 (c)

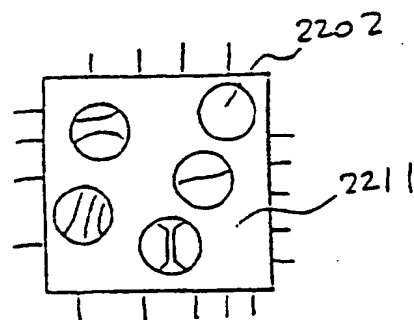


FIG. 22 (d)

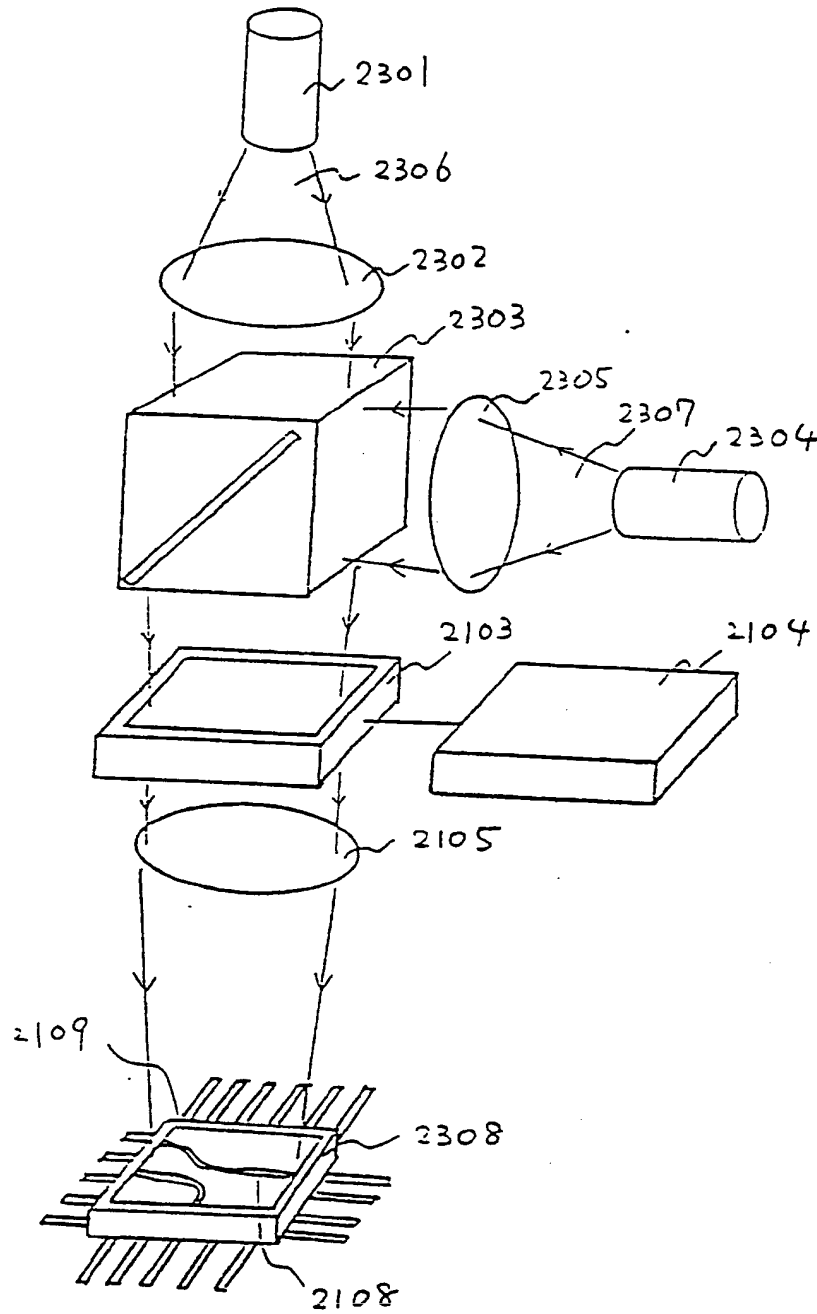


FIG. 23

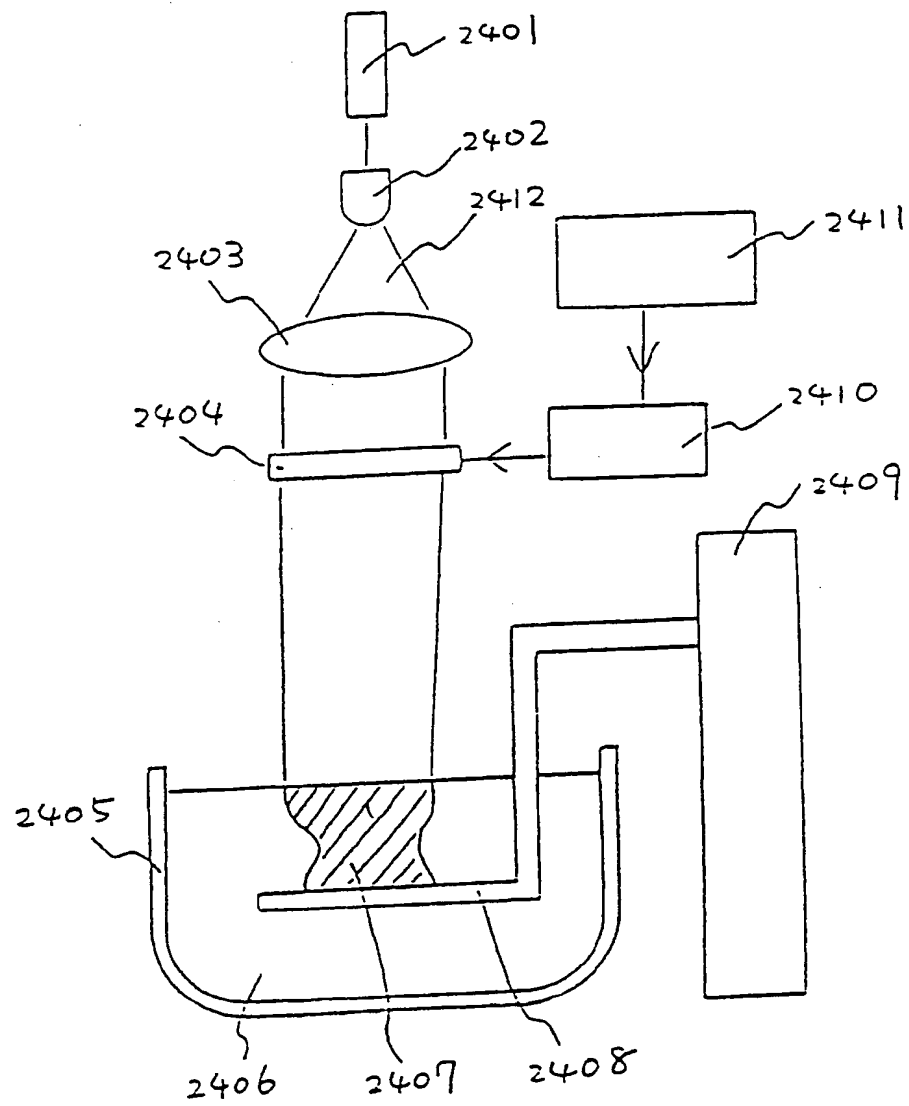


FIG. 24

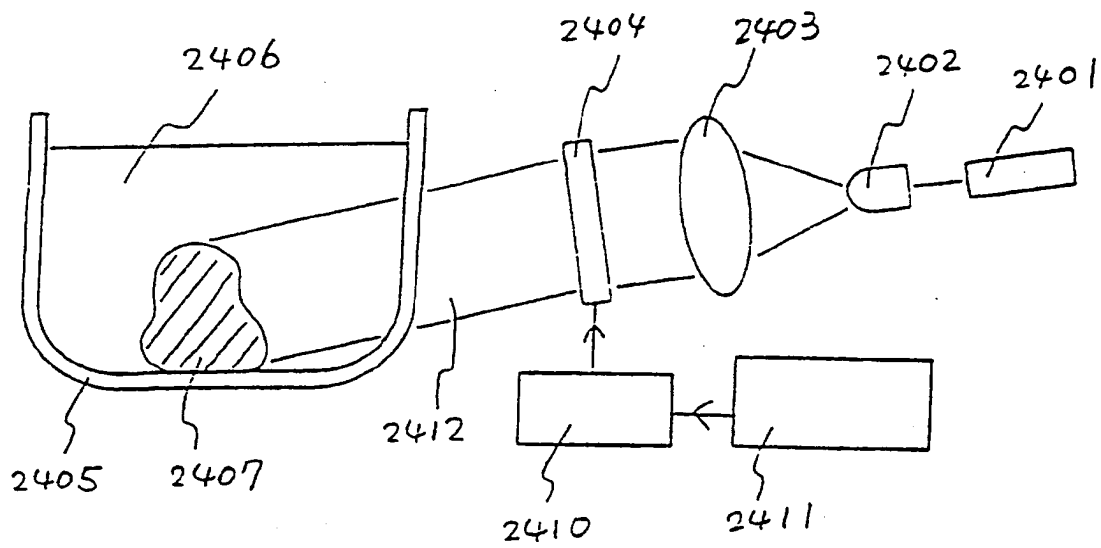


FIG. 25



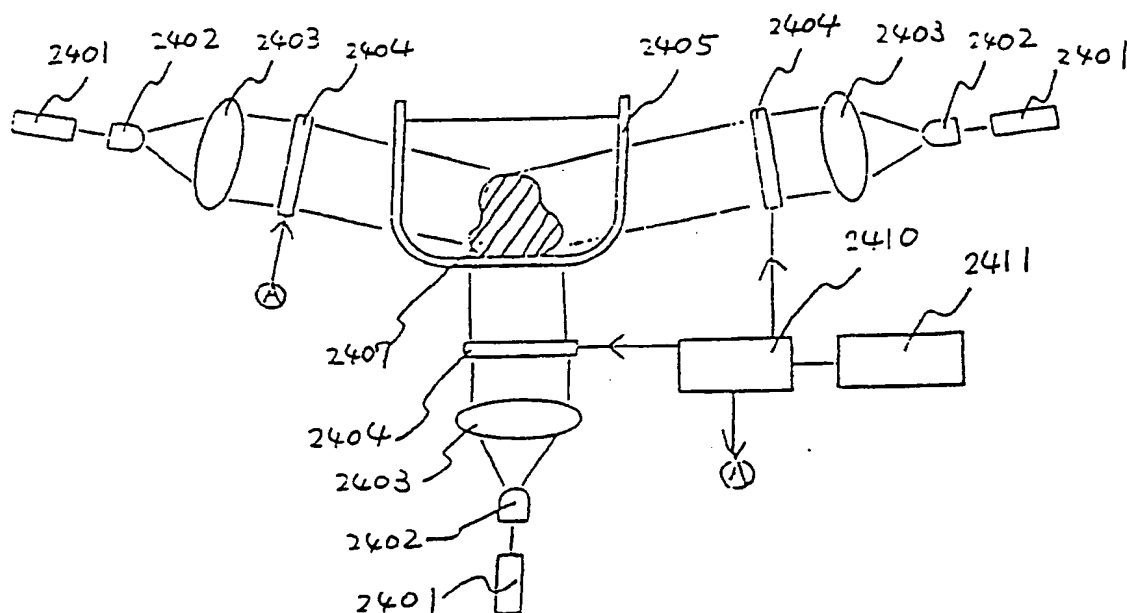


FIG. 26

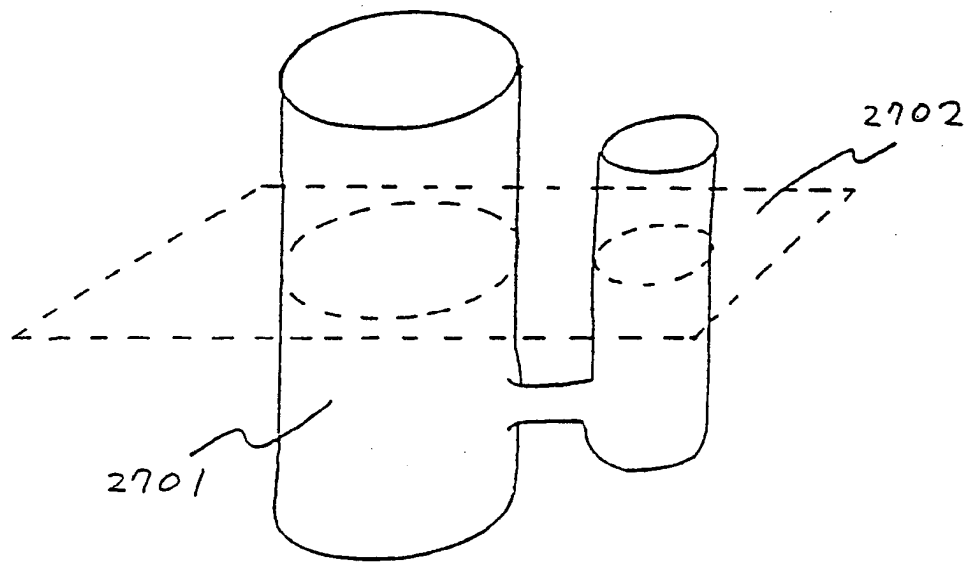


FIG. 27 (a)

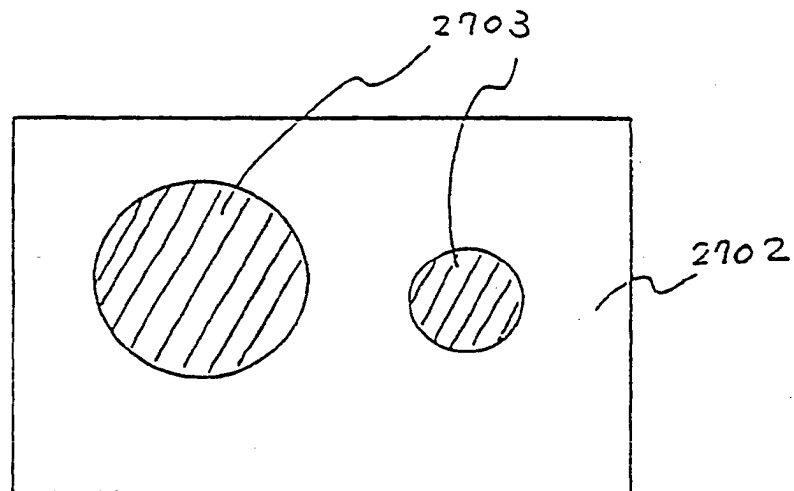


FIG. 27 (b)

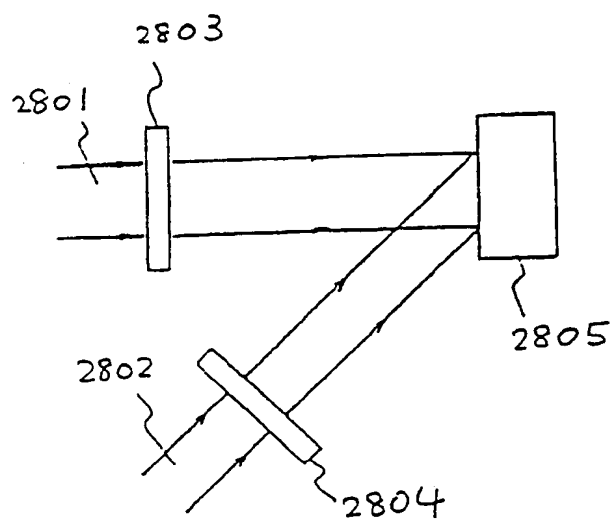


FIG. 28

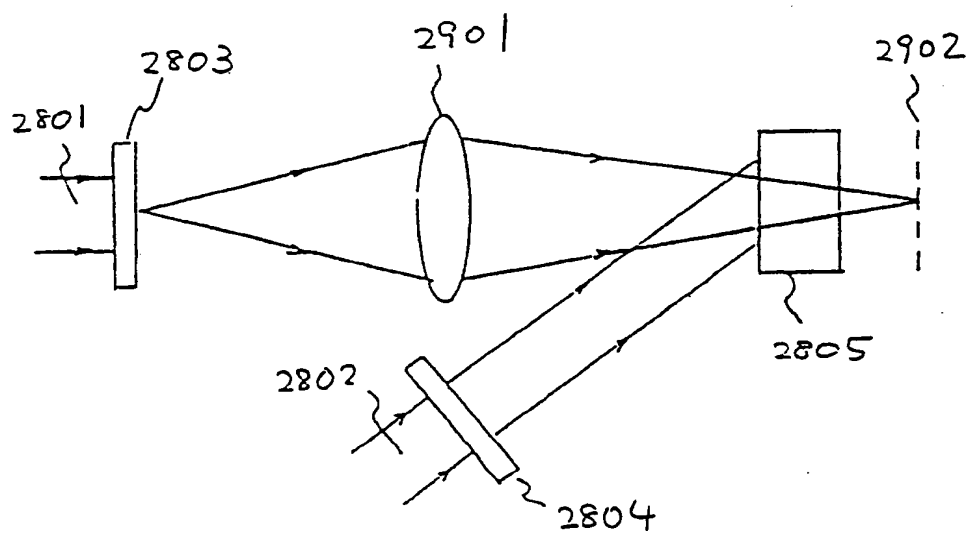


FIG. 29

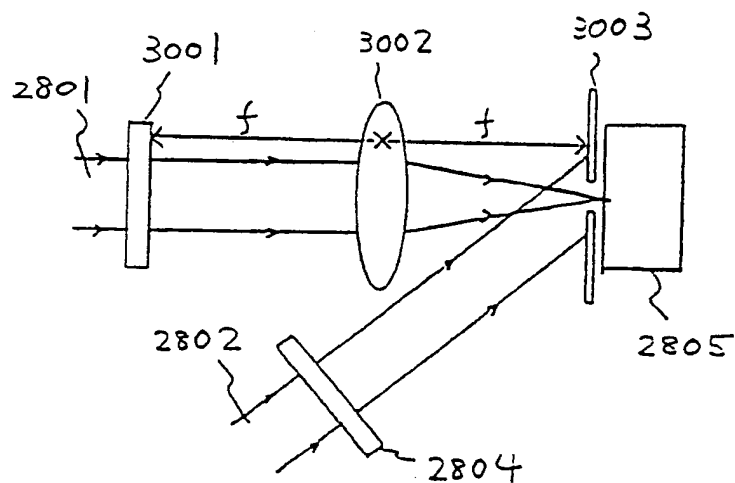


FIG. 30

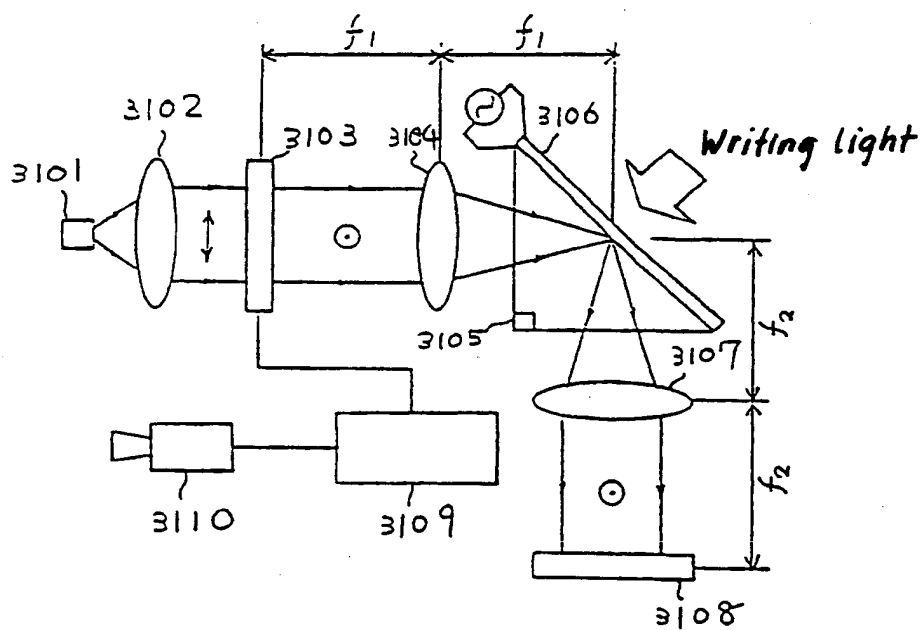


FIG. 31

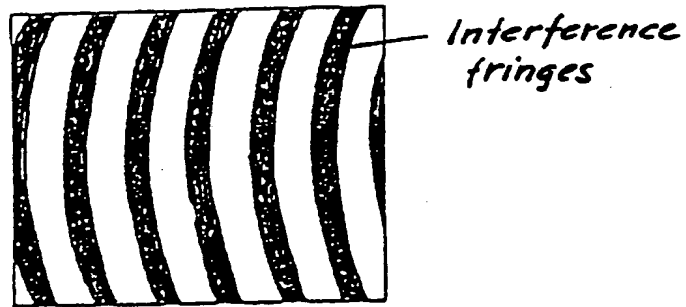


FIG. 32

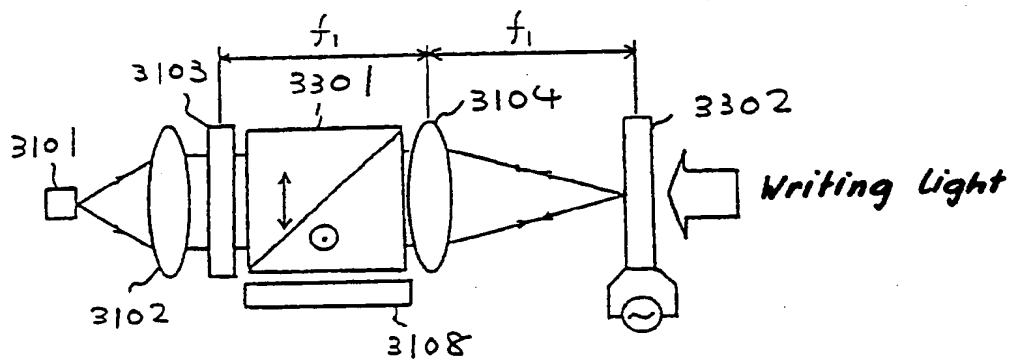


FIG. 33

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G02B 5/32, G03H 1/08,  
G02F 1/29**

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**14.11.90 JP 307836/90**  
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(54) **Optical apparatus.**

(57) An optical apparatus for controlling a wave front of a coherent light includes at least a coherent light source (104), an electrically addressable liquid cry-

stal device (106) having a plurality of pixels, and a signal generator (101-103) for recording a complex amplitude distribution on said liquid crystal device.

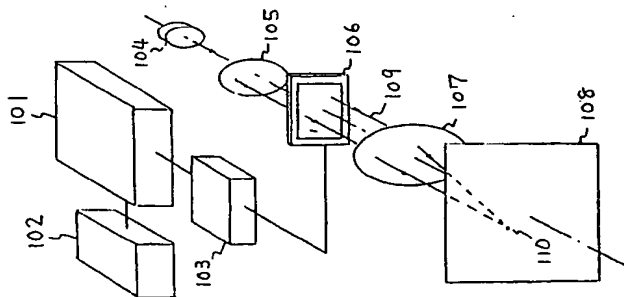


FIG. 1

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. CL.5)
X	APPLIED OPTICS, vol. 28, no. 15, November 1989, NEW YORK, USA pages 4845 - 4852; TH.H. BARNES ET AL.: 'Phase-only modulation using a twisted nematic liquid crystal television'	1-3	G02F1/135 G02F1/1347 G02B5/32 G03H1/08 G02F1/29
A	* pages 4845 - 4846, chapter I * * pages 4847 - 4851, chapters IV and V * * figures 6,9 * ---	4,6, 8-10,13, 22	
X	APPLIED OPTICS, vol. 25, no. 9, May 1986, NEW YORK USA pages 1380 - 1382; A.M. THAI: 'Low-cost LCD spatial light modulator with high optical quality'	1,3	
A	* the whole article * ---	2,8,9,22	
A	WO-A-8 912 249 (HUGHES AIRCRAFT COMPANY)  * page 1, line 6 - line 9 * * page 2, line 29 - page 3, line 25 * * page 4, line 26 - page 5, line 1 * * page 5, line 26 - page 7, line 6 * * page 9, line 9 - page 12, line 22 * * figure 1 * ---	1,6-9, 11,23, 25,30	TECHNICAL FIELDS SEARCHED (Int. CL.5)  G02F G02B G03H
A	P. HARIHARAN 'Optical holography' 1984, CAMBRIDGE UNIVERSITY PRESS, CAMBRIDGE * pages 113 - 115, chapter 7.7 * ---	1,18,19, 23,26	
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The present search report has been drawn up for all claims			
Place of search THE HAGUE	Date of completion of the search 31 MARCH 1992	Examiner VOLMER W.	
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X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- @ : member of the same patent family, corresponding document	

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A	APPLIED PHYSICS LETTERS, vol. 42, no. 9, May 1983, NEW YORK, USA pages 807 - 809; S. KOMURO ET AL.: 'Study of optically induced degradation of conductivity in hydrogenated amorphous silicon by transient grating method' * the whole article *	1,18,20, 23,26	
A	EP-A-0 125 692 (NEC CORPORATION) * page 12, line 7 - line 27 * * page 20, line 11 - line 24 * * figures 2,6 *	2	
P,X	JAPANESE JOURNAL OF APPLIED PHYSICS, vol. 29, no. 8, August 1990, TOKYO, JP pages 1533 - 1535; J. AMAKO, T. SOMEHARA: 'Computer-Generated Hologram Using TFT Active-Matrix Liquid Crystal Spatial Light Modulator (TFT-LCSLM)'	1-4	
P,A	* the whole article *	8,9	
E	EP-A-0 450 644 (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.) * page 2, line 58 - page 4, line 25 * * page 5, line 3 - page 6, line 3 * * page 6, line 46 - page 7, line 6 * * figures 2,3A,5 *	1,3,23	
P,A	JAPANESE JOURNAL OF APPLIED PHYSICS, vol. 29, no. 7, July 1990, TOKYO, JP pages 1231 - 1234; T. SONEHARA: 'Photo-Addressed Liquid Crystal SLM with Twisted Nematic ECB (TN-ECB) Mode' * the whole article *	1,5-9, 23-25, 28,30	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 31 MARCH 1992	Examiner VOLMER W.
<b>CATEGORY OF CITED DOCUMENTS</b> X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons * : member of the same patent family, corresponding document			

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